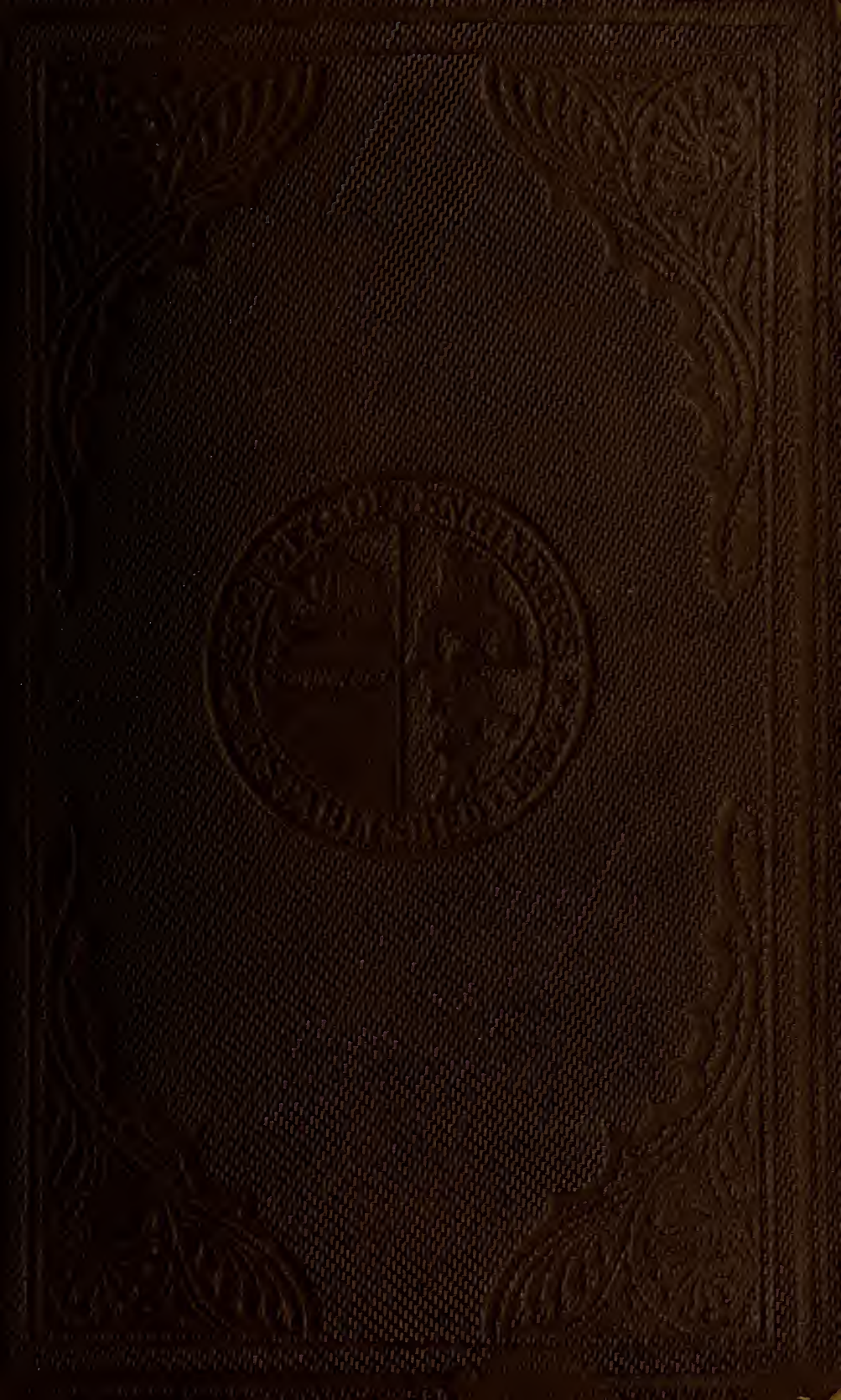


REMOTE STORAG
THE UNIVERSITY
OF ILLINOIS
LIBRARY

G20.6
SO
1887
cop. 2

ENGINEERING
ALTGELD HALL ANNEX LIBRARY

Geo. F. Chapman

SOCIETY OF ENGINEERS.

ESTABLISHED MAY, 1854.

TRANSACTIONS FOR 1887.

EDITED BY

CHARLES J. LIGHT, MEMB. SOC. ENG.,

SECRETARY.

E. & F. N. SPON, 125, STRAND, LONDON.

NEW YORK: 12, CORTLANDT STREET.

1888.

G20.6
SD
1887
Cop. 2

REMOTE STORAGE

PREMIUMS FOR 1887.

At a meeting of the Society, held on February 6th, 1888, The Bessemer Premium of Books was awarded to:

EDMUND OLANDER, Assoc. M. Inst. C.E., for his Paper on "Bridge Floors; their Design, Strength, and Cost."

The President's Premium to:

R. M. BANCROFT, Past President of the C. and M. E. Soc., for his Paper on "Renewal of Roof over Departure Platform of King's Cross Terminus, G.N.R."

A Society's Premium to:

EDGAR C. THRUPP, for his Paper on "A New Formula for the Flow of Water in Pipes and Open Channels."

And a Society's Premium to:

ROBERT JOSEPH HUTTON, for his Paper on "Stability of Chimney Shafts."

6 Feb. 1917 McGill

355354

CONTENTS.

PAGE

Inaugural Address of the President, Professor Henry Robinson 1

Bridge Floors: Their Design, Strength, and Cost. By Edmund Olander, Assoc. M. Inst. C.E. 27

The Shone Hydro-pneumatic Sewerage System. By Edwin Ault 68

Refrigerating Machinery on Board Ship. By T. B. Lightfoot, M. Inst. C.E... 105

Renewal of Roof over Departure Platform at King's Cross Terminus, G.N.R. By R. M. Bancroft 125

Vacation Visits 145

Stability of Chimney Shafts. By R. J. Hutton 150

Primary Batteries for Illuminating Purposes. By Perry F. Nursey (*Past President*) 185

A New Formula for the Flow of Water in Pipes and Open Channels. By E. C. Thrupp 224

Obituary 265

Index 267

SOCIETY OF ENGINEERS.

ESTABLISHED MAY, 1854.

Geo. J. Chapman,
Assoc. M. I. C. E.
with Compliments

NCIL AND OFFICERS FOR 1887.

Council.

esident.—PROFESSOR HENRY ROBINSON.

Vice-Presidents.
- ARTHUR T. WALMISLEY.
- ARTHUR F. PHILLIPS.
- M. OGLE TARBOTTON.

MS.	ROBERT HARRIS.
. BAILLIE.	WILLIAM BARNS KINSEY.
RINE BIRCH.	WILLIAM SCHÖNHEYDER.
WBY COLAM.	WILLIAM ANDREW VALON.

Members of Council, ex-officio.

Past Presidents ..
- PERRY FAIRFAX NURSEY.
- CHARLES GANDON.
- ARTHUR RIGG.
- JABEZ CHURCH.
- CHARLES HORSLEY.
- JOSEPH BERNAYS.

Past President, and one of the Founders of the Society .. HENRY PALFREY STEPHENSON.

Hon. Secretary, and Treasurer.—ALFRED WILLIAMS.

Hon. Auditor.—ALFRED LASS.

Secretary.—CHARLES JULIAN LIGHT.

Bankers.—MESSRS. LLOYDS, BARNETTS, & BOSANQUET (LIMITED).

Hon. Solicitors.—MESSRS. WILKINS, BLYTH, & DUTTON.

OFFICES:

9, VICTORIA CHAMBERS, VICTORIA STREET, S.W.

PLACE OF MEETING:

THE TOWN HALL, WESTMINSTER.

1888.

SOCIETY OF ENGINEERS.

ESTABLISHED MAY, 1854.

COUNCIL AND OFFICERS FOR 1887.

Council.

President.—PROFESSOR HENRY ROBINSON.

Vice-Presidents.
- ARTHUR T. WALMISLEY.
- ARTHUR F. PHILLIPS.
- M. OGLE TARBOTTON.

HENRY ADAMS.
JONATHAN R. BAILLIE.
R. W. PEREGRINE BIRCH.
WILLIAM NEWBY COLAM.
ROBERT HARRIS.
WILLIAM BARNS KINSEY.
WILLIAM SCHÖNHEYDER.
WILLIAM ANDREW VALON.

Members of Council, ex-officio.

Past Presidents ..
- PERRY FAIRFAX NURSEY.
- CHARLES GANDON.
- ARTHUR RIGG.
- JABEZ CHURCH.
- CHARLES HORSLEY.
- JOSEPH BERNAYS.

Past President, and one of the Founders of the Society .. HENRY PALFREY STEPHENSON.

Hon. Secretary, and Treasurer.—ALFRED WILLIAMS.

Hon. Auditor.—ALFRED LASS.

Secretary.—CHARLES JULIAN LIGHT.

Bankers.—MESSRS. LLOYDS, BARNETTS, & BOSANQUET (LIMITED).

Hon. Solicitors.—MESSRS. WILKINS, BLYTH, & DUTTON.

OFFICES:
9, VICTORIA CHAMBERS, VICTORIA STREET, S.W.

PLACE OF MEETING:
THE TOWN HALL, WESTMINSTER.

1888.

TRANSACTIONS, &c.

February 7th, 1887.

INAUGURAL ADDRESS.

PROFESSOR HENRY ROBINSON,

PRESIDENT.

GENTLEMEN,

In addressing the Society of Engineers from the Presidential Chair, it is my first duty to express my thanks for the compliment that has been paid me in electing me to that office, and to say how highly I appreciate the confidence that has been shown me in calling upon me to preside over the Society in this the year of the Jubilee of Her Most Gracious Majesty the Queen. It will be my earnest endeavour during my year of office to maintain the *prestige* of the Society, and to further its interests in every way in my power.

I assume the chair at a time when the Society is to be congratulated on its augmented numbers, on its financial prosperity, and on the rapidly extending field of its operations and usefulness. The increasing interest which is taken in its work is evidenced by the fact that its printed Proceedings are sought for wherever the English language is spoken, and wherever engineers are engaged in the discharge of professional duties.

During the past year Members have had opportunities of visiting places of great engineering importance. The hearty welcome which is invariably accorded to the Society on these occasions, and the efforts that are made, and successfully made, by which everything of professional interest is placed at the service of the Society, deserves special acknowledgment. These visits bring the Society into close touch with engineering works of first magnitude, and they prove instructive alike to the senior and to the junior members. The places thus visited were:—

The Tilbury Docks.

The Southwark and Vauxhall, and the Grand Junction Waterworks, Hampton.

The National Agricultural Hall, Kensington.

Messrs. Woodhouse and Rawson's Electrical Works.

Messrs. Westwood, Baillie & Co.'s (London Yard) Works, to inspect the Sukkur Bridge.

In making these visits the Members had the pleasure of recognising at the National Agricultural Hall the skill of Mr. Walmisley (one of our Vice-Presidents), who was associated with Mr. Max am Ende, in the novel design of the roof, and on the visit (which is the second the Society has paid) to Messrs. Westwood, Baillie & Co.'s Works an opportunity was afforded of appreciating the perfection of bridge work in the difficult construction of the Sukkur Bridge by the firm, with which one of our Members of Council (Mr. Baillie) is associated.

During the past year Papers of great interest were read and discussed, to the following of which Premiums were awarded:—

BESSEMER PREMIUM (*First Award*)

to Percy F. Tarbutt, A.M.I.C.E., for his Paper on "Liquid Fuel."

PRESIDENT'S PREMIUM (*First Award*)

to George B. Jerram, A.M.I.C.E., M.S.E., for his Paper on "River Pollution caused by Sewage Disposal."

SOCIETY'S PREMIUM

to Edward S. Bellasis, A.M.I.C.E., for his Paper on "The Roorkee Hydraulic Experiments."

I would remind Members that their interests as well as the Society's will be promoted by availing themselves of every opportunity for contributing Papers. The list of subjects which the Council defined in a Notice which was issued last year is sufficiently comprehensive to include all matters of professional interest.

A matter deserving of special mention is the arrangement that has been made with the Victorian Engineers' Association of Melbourne, on the basis of a partial affiliation of the two Societies, which will result in mutual advantage. This extension of the Society's sphere of activity indicates a direction for increased usefulness, and one which promises important results.

I address you at a time when lamentation is heard constantly on the falling off in professional work, and an expression of fear that the future for engineers is the reverse of bright and encouraging. I would like to direct a few remarks to remove what I think is an erroneous impression, and especially to disabuse the minds of the younger members of the profession of this feeling of discouragement, which naturally weighs on

them in consequence. I do not believe that there is any ground for looking gloomily upon the future of engineers. On the contrary, I predict with confidence a successful career for every properly trained, intelligent, and industrious member of our profession. Having myself, during the last twenty-five years, passed through three periods of profound depression in trade like the present (I am inclined to say the past), entailing a like feeling of anxiety and doubt as to the future of professional work, I have a vivid recollection that these previous dark periods were followed, and that suddenly, by times of great prosperity. The interval between the two periods, however, on these occasions, led many, I remember, to abandon the profession, either from inability to wait for better times, or from an erroneous notion that those better times would never come. My own experience has led me to think that probably most of those who discarded their profession in this way were really not fitted for it, or had no real love for it. Too many young men join a profession without having either a natural taste or a proper training for it. Either of these wants will diminish the chances of success in even good times, but will inevitably sooner or later cause them to come under the operation of the law which provides for the "survival of the fittest." The cause of failure on the part of even many who have a fondness for the profession (those who have not should never follow it) arises, according to my observation, from defective training. The engineering profession has so wide and varied a range of subjects coming within its scope, that it is essentially necessary for the education of those who intend to follow it to be a broad and a complete one. A combination of the theoretical or scientific, with the practical or constructive, is what should be aimed at. In too many cases one is allowed to predominate over the other. Many youths are sent almost direct from school into workshops; whilst on the other hand, many pursue their theoretical studies apart from opportunities of observing the practical application of their knowledge. In both cases an important factor in the formation of an engineering training is wanting. In the former, the youth may become a skilful mechanic, but will lack breadth of knowledge to fit him for a profession which has pre-eminently to deal with large subjects extending over a wide range of thought. In the latter, the youth acquires a higher proficiency in pure science than may be required for actual engineering work, and is wanting in the leaven of practical knowledge. The brain and the muscles, or the mind and the hands, should work together, as it is by a combination of the two that information obtained in early life is impressed on the mind in a form available for successful utilisation. It is necessary that a fair know-

ledge of science, draughtsmanship (the language by which engineers transmit their thoughts), and the use of tools, should be cultivated. In my judgment, the theoretical and practical elements in the training of an engineer, up to say eighteen years of age, should go hand in hand, under circumstances which enable him to acquire theoretical and scientific knowledge in conjunction with the practical experience of workshops or engineering laboratories. At the end of such a course, which would bring the youth to the age before mentioned, his training should be matured by passing two or three years with a civil engineer in full practice, if his intention is to follow civil engineering; or if he elects to be a mechanical engineer, then he should pass his time in large works. It should not, however, be thought that in either case the training fits a young man to start in independent practice. It has brought him to the stage when his services have a value sufficient to enable him to be employed by his chief in positions and under circumstances which he could not occupy if he had been articled without a previous technical training. On the Continent the schools of technical training aim at completing the professional education, but I do not consider it possible in any educational establishment to impart to, and impress on, the mind the results of the matured experience of actual practice, although a considerable approach to it can be accomplished.

Whilst public money has been employed, I might say lavishly employed, in carrying out the principle of the compulsory education of the masses in this country, at a nominal cost to them, the higher technical education of those who will in the future have to sustain the burden of contest with foreign competition in every walk of life, has not received the attention on the part of the State that the importance of the subject requires. The kind of instruction to which I refer is that which can only be imparted by the aid of technical laboratories and workshops thoroughly provided with the most modern, practical, and scientific apparatus. These are necessarily costly to provide and to maintain, and the skilled staff which alone can properly utilise such appliances, and instruct the students in the use of them, should be a well-paid, and therefore an expensive staff. I am of opinion that it is imperatively necessary that means of giving the technical instruction I have indicated should be provided by State aid and endowments, to enable the information which such establishments could impart to be afforded at a very low scale of fees. This can only be done by grants towards—1st, the original cost of such establishments; 2nd, the maintenance of them;

3rd, the remuneration of skilled teachers; 4th, the founding of scholarships, and to otherwise helping the students.

It is a fact that the principle of State aid which I am urging has been acted upon at various times, but in a way so singular as to deserve notice. The following table shows the way in which the State has aided the higher technical education in this country:—

ENGLAND.

Town.	Population.	Grant.
Birmingham	1,200,000	
Bristol	380,000	
Leeds	900,000	
Liverpool	1,600,000	No Government Contribution.
London	4,500,000	
Manchester	1,500,000	
Newcastle and Durham	800,000	
Nottingham	550,000	
Sheffield	450,000	
WALES.		
		£
Aberystwith	12,000	4,000
Bangor	60,000	4,000
Cardiff	380,000	4,000
SCOTLAND.		
		£
Aberdeen	120,000	3,811
Dundee	..	None.
St. Andrews	180,000	2,205
Edinburgh	260,000	6,604
Glasgow	700,000	3,465
IRELAND.		
		£
Belfast	210,000	8,500
Cork	170,000	8,500
Galway	20,000	8,500

From this table it will be seen how highly privileged are the centres of population in Ireland, Wales, and Scotland.

A Report of a Royal Commission in 1872 recommended the endowment of colleges like King's College and University College, London, and Colleges in several of the great industrial centres, but the recommendations have been neglected. Probably the importance of technical education as affecting the future position of this country, in regard to its trade and manufacture, will be at last recognised by carrying into effect the

carefully matured recommendations of this Royal Commission, confirmed as it is in a striking manner by the recent Report of the Royal Commission on Trade Depression, in which it is clearly pointed out that the foreigner has a better technical and commercial education, and that our reputation for excellence of workmanship is deteriorating. I hope that ere long the much needed pecuniary aid will be granted by the State towards extending the usefulness of the many engineering schools which exist, and bringing them within the reach of numbers whose limited resources prevent them having that preliminary technical training which would both smooth their way in their professional career, and which would also produce a higher order of work from them than is otherwise possible. I hope to see the establishment of a Teaching University for London, to include within it all recognised bodies who are engaged in scientific teaching. In conjunction therewith I support the proposal for conferring a Degree of Engineering. In this connection I consider the members of the profession should urge the Institution of Civil Engineers to take the initiative in regard to many matters which call for action, such as engineering education, granting diplomas, and maintaining some standard on the part of those who are enrolled in its body as to professional rules, etiquette, and the like. Many things occur in our profession which in the legal or medical profession would be impossible. These tend to lower the status of engineers, and imperatively call for a remedy.

I should advise young engineers not to endeavour to be specialists too soon. Let the training be broad enough to make the engineer competently informed in the groundwork of professional knowledge before a special branch is attempted to be followed. If this is not acted on the engineer would somewhat resemble the medical quack, who presumes to advise on one particular organ, or part of the human system, without a thorough knowledge of the laws which apply to the whole. Without a skilled and practised acquaintance with their dependence one on the other any attempt to remedy a special defect will be unsuccessful, as it would be were a novice in mechanics to endeavour to alter or modify the gearing of complicated machinery or apparatus without the full knowledge and experience of the principle on which the whole has been designed and constructed.

It is considered by many that the future of the railway engineer is not brilliant. In this country, it is true, there is no probability of there being any opening for constructing heroic lines of railway. There is, however, a wide and profitable field for engineering skill in perfecting and de-

veloping the existing systems. I consider that the engineers who are permanently attached to the various main lines of railway in this country have much to accomplish before the existing arrangements approach what the public require in regard to their comfort, convenience, and safety. Some companies (only a few, however) recognise that the wants of the travelling public have to be studied and provided for, and even catered for, as a matter of sound policy by which traffic is secured and developed. Many companies, however, do not thus popularise their lines, but regard the traveller apparently as one from whom the maximum is to be extracted for the minimum of consideration, comfort, or attention. In invading the territory of such companies by promoting competing lines, the engineer finds but little difficulty in gaining a favourable decision from a Parliamentary Committee; and as many large districts are now either suffering from a monopoly or from neglect, there is still a considerable opportunity for engineering ability in constructing main competing lines where they are justified by the circumstance of increasing population and manufacturing industries, as well as in developing the resources of districts by branch lines, tramways, and other feeders.

There are numerous districts which cannot bear the cost of the ordinary line of railway, and there are many where it does not suit the nature of the demand for tractive power which exists, as owing to great differences of level, or to the necessity for great economy, the introduction of an ordinary railway is practically barred. Throughout vast areas in this country tramways or light railways can be advantageously constructed, and where great differences of level exist the steep-grade system furnishes a ready solution of the difficulty, by enabling a fixed engine to provide the motive power for a series of cars through the medium of a cable. In the Metropolis the Steep-Grade Tramway at Highgate is a successful example of this system of traction, an interesting account of which was given to the Society in 1885 by Mr. Colam, the engineer to it. There is no doubt that where a very great traffic exists in our main thoroughfares cheap mechanical traction must in time be substituted for expensive horse traction. In fact, I believe that before many years are past the tractive power employed for drawing carriages and vehicles of all kinds, public and private, will be less and less the horse, and will be more and more derived from motors attached to the vehicle. The supposition that steam tram engines are either a danger or a nuisance should be regarded now as having exploded. We all know that steam cars can be constructed to work quietly and without annoyance. With reference to the cable system, the

Americans are far beyond us in recognising the advantages of its adoption. They have many steep-grade tramways at work in towns, at speeds varying from 7 to 10 miles an hour on fairly level lines, and at about 6 miles an hour on steep gradients of about 1 in 5. In Chicago there are upwards of 20 miles of single-line cable tramway in successful operation, a length of over 100,000 feet of cable being operated from one central station. In places the tramway branches off at right angles, no difficulty being experienced in working it with curves of a radius of only 31½ feet. Mr. E. Pritchard, who in conjunction with Mr. Kincaid has devoted much skill and attention to developing this system, visited America last year with the view of investigating the cable lines there, and of advising as to the introduction of the system in this country. At Birmingham a system of cable tramways is now being carried out in part substitution of existing lines, and to work at speeds of 6 and 8 miles per hour. The method of construction involves some special arrangements, which have been devised, and which indicate an advance in cable tramway construction.

In China, a cable tramway is in course of construction from the town of Hong Kong up to the "Peak," a range of very steep hills, on which are many fine residences and where the climate is better than at the low level by the harbour. The incline, which is 4800 feet long, is laid with 35 lb. steel rails on steel sleepers, the line being partly single and partly double. The gradients vary between 2 to 1 and 10 to 1, following closely the natural contour of the ground. The total height the carriages have to be raised is 1300 feet. Each car is to contain sixty passengers, the maximum load being 7½ tons at each end of the ropes. The speed of the cars is to be six miles an hour.

There is every prospect of railways and steam tramways being introduced extensively in China, as the Celestials appear to be recognising the advantages of steam locomotion. This indicates a great change, since the Shanghai and Woosung Railway (which was originally initiated by myself), after being at work most successfully for a short time, was purchased and destroyed by the authorities. In the near future I consider that there will be a great opening for railway enterprise in China. It is known that a model railway (provided by an English firm) supplies a permanent source of amusement in the official residence of the Tastai of Shanghai, and on the 22nd of last November, Li Hung-Chang formally opened an experimental line at Tientsin. As an official censor has already been rebuked for objecting to railways as innova-

tions, it is clear that Chinese obstruction is gradually, but none the less surely, giving way. An article by the Marquis Tseng, in the *Asiatic Quarterly Review*, confirms what I have said, and as it emanates from so important a functionary as the late Chinese ambassador, it may be regarded as having the weight of a state paper. The Marquis clearly indicates the intention of his government to accept the results of Western progress, by which the enormous resources of the Celestial Empire will doubtless be brought within reach of the enterprise of English capitalists and engineers.

The recent annexation of Burmah as part of the British Empire, has furnished an opportunity for the extension of the railway system. The construction by the Government of the line of railway from the termination of the existing Sittang Valley Railway at Tounghoo to Mandalay, by the route which was selected by myself and Mr. W. H. Thelwall, towards the close of the reign of King Theebaw, will develop the resources of this valuable addition to our Empire. I am of opinion that if the facilities which will be thus afforded are taken advantage of by the Government, British influence in the direction of the Celestial Empire will be consolidated, and a great opening will be secured for future enterprise both from an engineering and commercial point of view.

The functions of an engineer being to utilise the powers of nature for the benefit of mankind, he should not be wasteful of nature's gifts. He should not forget that the various changes in matter are based on the fundamental principle of correlation and conservation of energy, and therefore those forces which tend to produce motion should not be employed by him in a way that involves waste. The keen competition which English manufacturers have now to meet, demands that in the various items which tell upon the cost of production economies must be more and more effected. The preservation of our trading supremacy depends upon this being done, as we have to contend against foreign production in fields which hitherto were practically a monopoly for our merchants. Whilst foreigners now enjoy the advantages resulting from the adoption of our appliances, they have also the benefit of a more frugal and provident working class to deal with than exists in this country. A return which I have before me of the hours of labour in Belgium in every description of industry, beginning with the extraction of the raw material from the earth to its manufacture and disposal in various forms, shows the startling fact that out of 305,000 toilers more than one-half work over twelve hours a day. This does not mean solely that these workmen devote more time to labour than their English

fellow toilers, because the question of how much work is done in both cases would be raised. The important point is, that the machinery and plant of a large factory are utilised for a greater length of time, and this consideration is often lost sight of. The combinations that exist for improving the condition of the working classes, and for protecting their interests, deserve sympathy, so long as the efforts to improve one class are not unfairly directed to injure another. In fact, I would gladly see an extension of this principle in the direction of improving the status of that large class of unskilled labourers, whose position I think is not sufficiently considered by those who direct the machinery of Trades Unions. Strikes are decided on in the interest only of the skilled men, whose labours are requited at a rate which enables them to provide for a rainy day; but the unskilled labourer is at the mercy of every natural or artificial alteration in the demand for his work, and he is much less able to provide for the vicissitudes thus occasioned than is the skilled artisan. The constantly increasing number of labour-saving appliances tend both to produce manufactures at a greater rate than heretofore (and thus create what is condemned as over-production), and also to lessen the demand for manual labourers, both skilled and unskilled. These disturbances between supply and demand must adjust themselves naturally by the cessation of production, when it is beyond the demand, and by the shifting of the excess of labour to other fields. Any artificial provision of work by the State for the excess of population appears fraught with danger, as it creates a most undesirable dependence on the part of those who cannot find work upon some outside and extraneous agency, to solve the question of how and where work is to be obtained, a difficulty which will not, I think, be overcome by interfering with the laws of supply and demand.

Economy should be effected in the production of the power required for actuating the innumerable machines which form the life-giving impulse of every industrial centre. Engine-makers have made rapid strides of late years in economising coal consumption, and, therefore, the production of power. This may be evidenced by the fact that whereas in the old Cornish bull engine upwards of 3 lb. of coal are consumed per indicated horse-power per hour, the modern improved compound engines consume only about $1\frac{1}{2}$ lb. Whilst this economy however is effected in the steam engine producing the power, a wasteful system exists in the distribution and utilisation of it. Each consumer has his own engines and boilers, whereas, if several consumers co-operated together, both the waste of power and of the cost of producing it, which obviously

must exist, would be prevented. By what I have termed power co-operation or centralisation, an installation of power at one point in a district produces the energy that is requisite for the wants of a large number of small and scattered centres of consumption, each of which has its independent boilers and engines, with the consequent occupancy of space, and with the attendant trouble and risk. By concentrating at one point the engines and plant that are requisite to meet a large consumption of power, it can be produced more economically than is the case with separate and smaller engines. The consumption of fuel for a large engine of 1000 horse-power could be brought to, say, 1½ lb. of coal per indicated horse-power per hour. Nothing approaching this would be possible in the case of, say, 100 small engines of 10 horse-power each. This has been definitely established by a careful investigation that was made at Birmingham, a short time ago, with reference to the proposal to carry out an extensive system of distributing power by compressed air (referred to more fully hereafter), when it was found that the consumption of fuel in engines ranging from 10 to 25 horse-power varied from 8 to 36 lb. per horse-power per hour. This was due to the fact that steam had to be kept up constantly to work engines, which were more or less intermittently utilised, at all events to their maximum capabilities.

Steam is employed for power distribution, and for domestic purposes, on the co-operative system. Boilers concentrated at one point produce the steam for consumption within moderate distances, the pipes conveying it having to be carefully protected, otherwise great loss from condensation ensues. An important illustration of this system is that of the New York Steam Company, which, by means of central stations, produces steam for working motors and for heating, cooking, &c., over the areas commanded by such station. Mr. Emery, the engineer to this company, has devoted much skill in overcoming the objections due to the presence of water from condensation. He passes the steam through a drum, as large as the steam space of the boiler in which the same quantity of steam would be ordinarily generated, by which the water is separated by gravity. The pipes in this case carry a steam pressure of 100 lb. to the inch, although 80 lb. has been adopted as the standard pressure.

The employment of liquid fuel for steam-generating purposes, as an alternative to coal, is gaining ground, as its capabilities and the means of applying it become better understood. The valuable paper of Mr. Tarbutt, read before the Society last year, threw much light on this subject. By his furnace

and system of injection it is manifest that liquid fuel, either in the shape of natural petroleum, or in other forms, is capable of being relied on as an economical heat producer, especially for marine and stationary boilers. Although it occupies only slightly less space than coal, it has greater steam-generating properties. This will promote its ultimate success for steamships, as, bulk for bulk, it will serve for longer voyages, and it can be readily taken on board. In warlike operations, too, the smokeless nature of its combustion is important. Petroleum may be regarded as a factor in dealing with the fuel supply of the world in the future, both for purposes of peace and war. It may be thought that this will represent an injury to the trade of this country by diminishing the demand for coal; but it is probable that the benefits to one class, derived from the facilities and economies which liquid fuel can effect in the means of producing steam for the enormous carrying trade of this country, will counterbalance the injury which may be done to other classes.

The utilisation of the gas in the mains of gas companies affords another instance of the principle of power co-operation, and the address of our past President, Mr. Gandon, affords a masterly summary of matters affecting gas interests. The improvements which have of late years been made in the gas engine render it a very convenient appliance for motive power, more especially where the work to be done is small, or where it is not worth while to lay down an independent installation of another medium. Gas engines of the best type will form a more important motor in the future than in the past, inasmuch as the loss that arose from the absorption of heat in the water jacket (representing as much as 60 per cent.) has been greatly reduced in the Atkinson Differential Engine. Further, by using the air gas of Dowson, or the oil gas of Rogers, the cost of the gas itself is reduced. Our past President, Mr. R. P. Spice, brought before us last year an excellent account of the most modern improvements in the manufacture of coal gas. He pointed out the success which he had accomplished in the purification of gas in closed vessels, by carbonising coal with a small percentage of slaked lime mixed with it before charging the retorts; the frequent opening and cleansing of the purifiers thus being obviated. The Gas Light and Coke Company have determined to place at Mr. Spice's disposal one of their metropolitan stations for an experimental trial on a working scale of the coal liming process.

To pass on to another and important means of effecting power co-operation. The hydraulic accumulator may be taken as an excellent illustration of the principle of conservation of

force with reference to the employment of water-pressure to actuate hydraulic machinery. The supply of water at high pressure from a hydraulic pump being continuous, and the abstraction of it from the mains being practically intermittent (however short the intervals of time may be), the period between the production of the power and its consumption enables the pressure to be maintained, and the surplus energy to be stored by raising the ram of the accumulator.

The principle of co-operation by hydraulic power has been successfully illustrated in a variety of works, where mechanical energy is required to be transmitted and utilised intermittently over great areas. By means of a pressure-main, a supply of power can be conveyed from a central station to actuate appliances at remote points. This is familiar to you all in regard to its application to docks, railway termini, and the like, but its extended application to towns for power co-operation, amongst numerous consumers, is now becoming well recognised. Under an Act of Parliament I carried out at Hull, a few years ago, the first work of this kind, and the success which has attended this pioneer work is resulting in similar ones being adopted in other towns. I have advocated this principle for more than a quarter of a century, and it is with great satisfaction that I see the system steadily gaining ground.

The extended utilisation of water power for raising canal boats, railway trains, passenger and goods cars, has come into prominence of late years, and with the increase in the weights to be lifted has arisen a difficulty in manufacturing presses capable of standing the enormous strains to which they are subjected. The limitation to the thickness of cast-iron cylinders to meet increase of strain has led to the introduction of the hooping of the presses, and also to the use of compressed molten steel. A notable case is that of the Hydraulic Canal Lift, now being constructed by Messrs. Clark, Standfield and Clark at La Louvière, on the Canal du Centre, near Mons, in Belgium. The huge presses for this lift are constructed in a novel manner. Rolled soft steel coils 6 inches deep are bolted together and shrunk over the cast-iron body of the press, which acts as a water-tight lining, and gives stability to it as a column. The feed-inlet is also provided for in a novel way, by which the usual weakening of the press at that point is avoided. A circular supply-tube surrounds the press, and from it several smaller tubes serve as feed-pipes, conveying water pressure to the interior without weakening the press, and also affording a more uniform supply, as the water flows into the press from many different points.

There is a great opening for hydraulic power in the direction

of working passenger and vehicular lifts for subways, by which the cost of heavy approaches and other works is capable of being greatly lessened. In this field of engineering labour Mr. Greathead has rendered much service. His proposed subway with hydraulic lifts for improving the Thames communication at Tower Hill deserves special mention, as affording a continuous means of providing for vehicular traffic by arranging the lifts in series, so that the continuity of the traffic is maintained.

The high-pressure hydraulic tools on Tweddell's system, enable the various operations of rivetting, flanging, bending, shearing, and the like, to be carried on with great perfection and rapidity. In ship construction the advantage of hydraulic riveting is very marked as compared with hand work, as, by machine riveting, steamships can be made of far greater strength and stability. This is imperatively called for to meet the increased strains and vibration to which ships are now subject by the constantly increasing power of the engines, as well as by the shocks and strains induced, or produced, by heavy ordnance. Hydraulic power has recently been adopted on board the larger class of merchant ships and passenger steamers in substitution of hand or steam machines, by which the same facilities for rapid discharge of goods from the ship itself are provided as have long existed on the wharf or place of discharge on shore. The enormous power that is available at the Niagara Falls is proposed to be utilised to a partial extent by means of hydraulic mains. This natural source of power has long engaged the attention of engineers, and the practical steps that are now being taken will, I have no doubt, prove a great step in advance of the well-known utilisation of the power of the Rhine at Schaffhausen.

In my recently published book on 'Hydraulic Power and Hydraulic Machinery,' I refer very fully to the interesting observations that have been made in recent years as to the behaviour of water, either when flowing in pipes under pressure, or when issuing from an orifice. Also as to the influence of temperature upon velocity, and the determination of the point at which "critical velocity" arises, when eddies develop, and, consequently, useful effect is diminished. Recent observations have cleared up some points, which had been previously obscure, as to the flow of water under pressure, and I will mention that formulæ are given in my book to meet the circumstance that the friction of water does not always vary as the square of the velocity, as is generally understood.

A remarkable example of power co-operation for transmitting fluid to distances is afforded by the oil producers in America, under the National Transit Company, who control upwards of

1300 miles of mains (varying from four to six inches in diameter), with about 9000 miles of subsidiary pipes two inches in diameter.

Compressed air affords a very convenient means of transmitting power. Its successful employment for working almost every variety of motors has led to its application on a wide scale, for the purpose of power co-operation, in a similar way to that which I have already stated that I carried out at Hull. Large works for distributing compressed air are now being carried out at Birmingham (under an Act of Parliament) by myself, in conjunction with Mr. John Sturgeon. Over an area of about $1\frac{1}{2}$ square miles compressed air at 45 lbs. pressure to the square inch above atmosphere will be distributed by mains varying from 24 to 7 inches diameter. The works are laid out for 15,000 gross indicated horse-power, of which 6000 horse-power are already being carried out. A railway siding brings slack coal to thirty-one of Wilson's 8 cwt. gas-producers, arranged in rows, and so placed that the coal is tipped direct from the waggons on the siding to the charging platform at the top of the producers. The gas from the producers passes through underground flues to the furnaces of the boilers. The gas-producers play an important part in the regulation and equalisation of the power, as there are, of course, some fluctuations in the demands upon the engines and compressors. At meal times, for instance, there is a general reduction in the demand, which is recovered again on resuming work. When the demand lessens, the air pressure rises, and an automatic governor comes into play, reducing the speed of the engines, and consequently the consumption of steam. The steam pressure would therefore rise in the boilers, but as an automatic damper would not meet the case, because the gas-producers would still go on manufacturing the gas at the old rate, the following plan is adopted: The steam injection to the gas-producers, upon which depends the consumption of fuel and the production of gas, is taken from a separate low-pressure hand-fired boiler (required also for starting the producers), and is governed by the air-pressure, by means of a rising and falling valve, so that when the air-pressure rises the steam injection, and consequent production of gas, is reduced. The fires under the boilers are thereby lowered throughout the whole range, and the steam-pressure is reduced. When the air-pressure falls the steam injection is increased, and the fires are raised simultaneously, the steam pressure being thereby increased. The whole is effected automatically and rapidly, according to every variation of the air-pressure.

The boilers which are on the ground level underneath the

engine-houses, consist of forty-five of Lane's water-tube boilers, in sets of three to each engine-house. There will eventually be fifteen engine-houses, each constructed to receive one triple expansion beam air-compressing engine of 1000 indicated horse-power, driving six single-acting air-compressing cylinders, coupled to opposite ends of the beams, and capable together of delivering 2000 cubic feet of air per minute, at 45 lb. above atmospheric pressure. The free air is drawn into the compressors through casings from the top of each engine-house, in which are inserted filtering screens to clear the air of solid impurities before it passes into the compressors.

The compressed air is supplied to consumers through meters of a construction somewhat similar to that of a Beale's Gas Exhauster, giving a very fairly accurate measurement, by piston displacement, of the volume of air used. As, however, the air will be sold at a price per 1000 cubic feet at the standard pressure of 45 lb., and as the pressure might sometimes vary, it is necessary to correct the reading of the meters in accordance with any such variations. For this purpose, a simple form of integrating gear is attached to the counting gear of each meter, by means of which, if the pressure falls below 45 lb., the volume measured is less in proportion to the diminished pressure.

To detect and remedy any leakage of air from the mains, all the various meter registrations throughout the district are registered in the gross upon a main counter at the central station, by means of an electric apparatus brought into action by a contact maker on every meter, at each 1000 cubic feet it measures off. In order to render the action instantaneous, and to prevent the apparatus being held out of action by the stopping of any meter on the point of contact, a small disengaging magnet is applied to each meter by which the contact maker is released by the same current that actuates the counter at the central station. By these means the total approximate volume of air measured to consumers can be daily or hourly ascertained, and compared with the delivery from the engines, as ascertained from continuous counters.

An application of compressed air to the automatic working of clocks, on what is known as the Popp system, deserves mention, as being of great interest, and with which the name of Mr. Wilfred Airy is associated in this country. In Paris several thousand clocks are worked from a central station by compressed air, which is conveyed under the streets by small pipes. A piece of tubing is attached to a small bellows in a simple clock mechanism, and is connected with an air main. These bellows are inflated once every minute by means of a puff of air, thus causing the minute hand to move forward.

The supply of air is admitted and cut off by mechanism connected with a central clock, which is regulated by time-signals from the observatory. The mechanism of the clock consists simply of the tiny bellows and spur-wheels. In Paris, the air is compressed at a station outside the town, and is then led by a four-inch main to a central station in the town, whence a network of pipes is laid in the streets, from which small service pipes lead into the houses and so to the clocks. These clocks are supplied, driven, and kept in order for a small annual tariff, and one which is very much smaller than most people pay now-a-days for keeping their clocks going. The modern clock costs a good deal of money to begin with, a great deal to repair it and keep it clean, and in many establishments an annual sum is paid to keep the clocks wound up. All these expenses are included in the moderate tariff charged for the compressed-air clock. A large number of clocks belong to the Municipality of Paris, and are placed at the crossing of streets, in squares, and in other public places. The system is in use over an area about one and a half miles long by three-quarters of a mile wide, and twenty or thirty miles of pipes are used, the largest clock pipe in the system being one inch in diameter.

The Shone system of compressed air ejectors is an adaptation of compressed air for the purpose of automatically raising fluid from one level to another, at places remote from the point of power production. Its recent application to the draining of the Houses of Parliament is an interesting instance of its successful employment.

The better conservation of the force of the wind, and the probable utilisation of the force of the tide, afford openings for the ingenuity of engineers. Practical difficulties attend the application of the power of the tide, as the works that are necessary to be employed to store tidal water at high tide, and to convert it into rotary motion as it descends, are, as a rule, too expensive to pay for transmitting power to distances. There are cases, however, which admit of the tide being utilised for power purposes close at hand, for raising and distributing water for irrigation and farming operations. For draining land the wind is capable of being utilised to a much greater extent than is now done. The utilisation of the sun's rays has attracted the attention of experimentalists for years, and Mr. Werdermann (the electrician) successfully put up an apparatus at Perim, in the Red Sea, for distilling salt water. Captain Erichsen has more recently, in America, arranged a boiler for generating steam, by focussing the sun's rays by a concave mirror arranged to follow the course of the sun. There are many places where the continuance of the sun's rays may be

relied upon, over a sufficiently long period, to justify the necessary mechanism being applied.

In agricultural pursuits I think there is an opening for the application of the principle of conservation of energy. It is quite certain that all who have a stake in land, either as landlords or tenants, must regard the future as necessitating wide concessions, and the introduction of capital from outside sources, owing to the unfortunate fact that the capital of the farmer must, to a very great extent, have disappeared. The extent to which the agricultural interests are affected is shown by the Report of the Royal Commission on Trade Depression, from which it would seem that the British farmer has forty millions less income than previously. The horse may be regarded as a machine whose co-efficient of useful effect is less, and whose co-efficient of depreciation and derangement is higher than most of the ordinary labour-saving appliances. Agricultural labourers may be classed under the head of machines, which produce the minimum of useful effect at the maximum cost for maintenance. There is no reason why the power that is required for farming operations should not be developed at a central point, either by a steam engine, water-power, or wind-power, and conveyed over the farm by small pipes, which can be shifted about (being made with flexible joints) to the places where it is required to be utilised for ploughing, harrowing, chaff and root-cutting, and for all the numerous purposes for which power is required. I believe that the day is not far distant when some of the vast capital awaiting investment will, through the medium of more scientific farming and a freer use of the mechanical aids at disposal, breathe a new life into British agriculture.

Electricity has a future before it for transmitting power. Successful electrical distribution lies in employing currents of high potentiality in small quantity, and with small conductors, in a manner comparable with the distribution of high-pressure water which I have already referred to. The difficulty of conveying great electrical force to distances by small conductors is due to the danger of fusing the medium by the heat due to the resistance, which increases with distance. Another loss, which has been minimised by Dr. Hopkinson, arises between the dynamos which receive power from the engine or other motor and the other end of the system where it is delivered. It is interesting to record the fact that M. Marcel Deprez has succeeded in developing electrical energy with only one generator and receptor, and in transporting to a distance of 35 miles a force of 52 horse-power at an efficiency of 45 per cent. This is accomplished without exceeding a current of 10 ampères with a maximum electro-motive

force of 6290 volts, and without accident at this high tension. One direction in which electrical energy will be capable of successful commercial utilisation is by means of secondary generators to enable the initial energy to be applied to the requirements of each consumer, the apparatus for distributing the energy being adapted to meet the conditions of varying or different resistances. Professor Forbes has stated that some secondary batteries are now supplied which can be relied on to give an effective return of 70 to 80 per cent. That this can be accomplished is evidenced by what has been done at the Vienna Opera House. I would also refer to the experiments which have been carried out on a large scale by the Edison Company at Milan, to light the Dal Verme Theatre, by means of alternating current transformers. These deserve mention, and appear to prove that the distribution over long distances, by means of transformers, can be effected similarly to the ordinary Edison Tube system over small distances.

The heavy cost attending the transmission of energy by means of electricity points to the alternative method of storing the energy in accumulators for transportation to the place of utilisation. This is being effected to a certain extent already. In the next few years, I think, a great advance will be made in the solution of many of the problems which are now exercising the minds of some of our best thinkers, and I am hopeful that a successful result will attend their labours.

Improvements are daily being effected in the direction of perfecting the details of dynamos and of the various apparatus connected with electrical distribution, under the stimulus of competition, and of the keen criticism of many who are not disposed to favour electric lighting.

The employment of electricity for purposes of locomotion deserves mention. America, I believe, can claim to have constructed the largest electric locomotive that has been made, and this was constructed at the Rhode Island Locomotive Works, the gauge being the same as for ordinary locomotives. It has six wheels, each 68 inches in diameter. Two electric motors coupled together give a joint power of 500,000 watts, or about 670 horse-power. The armatures of the motors are 3 feet in diameter, and act directly on the axles without intermediate gearing. The locomotive is provided with electric head-lights, bells, and tubular brakes, worked automatically by electricity. The train to which this locomotive is to be applied is to be lighted by incandescent lamps, and is fitted with electric brakes to every carriage. The power can be conveyed from the generating station either by a central conductor insulated in the air or by an underground one.

The Newry and Bessbrook Electric Railway is another important illustration of the employment of electricity to locomotion. This line is three miles long, and the electrical energy to work it is derived from a mill-race working a turbine of 65 horse-power to actuate the generating dynamos, which are of the Edison-Hopkinson type. The current from the generating dynamos is conveyed from a switch-board to a centre rail which runs the whole length of the line, and midway between, and on a level with, the rails on which the flange-wheels of the car travel. The electrical rail runs along the ground, and in addition to the rails on which the cars run there are two outer rails at a slightly lower level. On these outer rails the goods wagons run, which have flangeless wheels, to enable them to be drawn on ordinary roads when they are off the railway. The current is conducted from the centre rail to the dynamos on the cars, which are capable of generating power up to 25 indicated horse-power, and they alone have electrical contact. The car is geared so as to run at a maximum speed of 15 miles an hour. The maximum gross load is 26 tons, the electrical locomotive being 8 tons. Two cars, capable of carrying thirty-four passengers, constitute the train. The full load can easily be taken up inclines of 1 in 85 at 7 miles per hour, and can be started on a gradient of 1 in 50. For traction purposes underground, either in mines or tunnels, where the question of ventilation is an important factor, electricity, like compressed air, will be more and more used. An electrical tram engine on Elieson's system is now at work on the Manor Park line of the North Metropolitan Tramways Company, and has no doubt been seen by many of you. This draws a tram-car with forty-eight passengers.

With respect to the employment of electricity for domestic purposes, the Act of 1882 tended to check electric lighting companies by imposing conditions more onerous than those that had been put on gas undertakings. It was impossible to obtain capital for a novel system like electric lighting when the local authority or vestry had powers of purchase more stringent than those obtained in regard to gas or water undertakings. The check, however, that was given was well deserved, owing to the too hasty way in which conclusions were being jumped at by those interested in promoting electric lighting. At a time when too sanguine a view was taken as to the economy of electric lighting, the Board of Trade were doing a service by imposing conditions which were not inconsistent with the financial success of the system if what was then stated by the promoters had been correct, which, however, was very far from being the case. Recent improvements in the direction of simplifying and economising the production of electrical

energy, I think, render the removal of the hampering restrictions of the Act desirable, by which encouragement will be given to the utilisation of the system with advantage. The public are now alive to the fact that the illusions which at first existed about economy have passed away, and that electricity recommends itself for employment for numerous purposes on the ground of convenience. The beauty and convenience of the various forms of lamps will prove too attractive to cause any question of cost to deter the more wealthy classes from indulging in the luxury of applying electric lighting to their mansions. The employment of it in this way will involve the greater use of either gas, steam, or water for working the dynamos, and will tend to an increased demand for the various means of actuating motors. I think that Electric Lighting Provisional Orders may now be prudently sought for by the Local Authorities themselves, who are free from the penalties imposed on outsiders.

The establishment of County Boards will, no doubt, soon come prominently forward and be dealt with by Parliament. It is expected that by this change Parliamentary work for engineers will be diminished, as many matters will be threshed out in the locality instead of by a Parliamentary Committee. It may, however, prove beneficial in the long run to our profession, as it is well known that many projects are not proceeded with, owing to the doubtful result of an appeal to Parliamentary Committees of two Houses. A joint Committee of both Houses has often been suggested as a better tribunal than duplicate Committees. In dealing with county government, the difficulty that will have to be overcome is to administer urban and rural affairs by one central authority. The difference between urban and rural affairs is very great, as is known by all who have come in contact with the boards which now have the control of the two. It is a mistake to assume that a town council or similar urban authority can easily have its boundary extended to include wide areas of rural population or small local boards. A new tribunal, formed on a basis commanding respect, in which the elective element would largely prevail, would be able to deal with the question of river pollution and other matters affecting the health of the community, which are at present hardly touched. In all elections to fill positions on County Boards I would confine the voters to those who are actually ratepayers. In political affairs the tendency appears to be to give every man a vote, but my experience of local boards and other authorities leads me to the opinion that any election based on universal suffrage would not result in the best men being returned for the purposes that a board has to grasp.

I will now refer to sanitary subjects for a few moments,

and will express the hope, which I am confident will be echoed by all who are engaged in matters of sanitary engineering, that the legislature will soon be able to expend some of its energies on much-needed reforms in reference to questions affecting the health of the community. There are several well recognised evils on which all are agreed that a remedy is within reach, and it is deplorable that year after year they are not remedied, and indifference is shown to what would tend to promote the real happiness and welfare of the people whether as classes or as masses. It would be beyond the scope of this address to indicate in detail what should be done; but I can state without hesitation, that sufficient agreement now exists in reference to much needed amendments of the Public Health Act of 1875, and of the Rivers Pollution Act of 1876, to enable them to be carried through Parliament without difficulty if only an opportunity was given.

The Rivers Pollution Prevention Act of 1876 was "An Act to make *further provision* for the prevention of the pollution of rivers," The "provision" referred to as then in existence had been wholly inoperative, as the House of Lords in 1876 recorded, in the preamble of a Bill, the fact "*that the pollution of rivers had lately so increased as to become a* NATIONAL EVIL," and the rivers in 1876 were far fouler than they were in 1873. During the last ten years the pollution of rivers has continued unchecked, and their condition now is much worse than it was in 1876. The main object of further legislation should be to render that "*further provision*" operative, so that the Act of 1876 may be enforced. No alteration should be made either in its peremptory prohibitions, or in the exemptions therefrom for the protection of sewer authorities, manufacturers, and miners using proper means for preventing river pollution. The removal of the restrictions contained in the sixth section would give vigour to the Act and efficacy to its prohibitions, and, by converting the permissive powers into mandatory requirements the effective operation of the law would be secured.

There is no longer any excuse for discharging sewage into rivers in an unpurified state, as the conditions which have to be observed in the purification of sewage matter are now well known, and are capable of being easily complied with.

The example of river pollution that has long been set by the Metropolitan Board of Works in its treatment of the river Thames is a scandal to the country. The most powerful representative authority in the world resisted for years the contention that the sewage of London was polluting the Thames. After it had been decided, on the authority of a Royal Commission, that their view was utterly wrong, they still have not

remedied the evil, but propose to adopt what appears to be a feeble system of precipitation accompanied by the removal of the sludge to the sea where it is to be got rid of and wasted. I trust that before any such scheme is adopted the Board will take steps to obtain guidance beyond that which as yet they appear to have sought for. At Glasgow a movement is on foot to prevent the continued pollution of the Clyde. It is contemplated to form the polluting area into groups of districts for the purposes of works of sewerage and of sewage disposal. Any movement is to be encouraged which indicates a departure from that state of apathy which has so long existed.

The question of water supply deserves a brief reference with the view of mentioning Dr. Dupré's new method of water analysis, by which organic impurity in water is determined by the amount of absorbed oxygen, the reverse of the previous method by which the amount of evolved oxygen was relied on for this purpose. Dr. Koch, on the other hand, feeds the organisms on gelatine, and by that means their existence, and the extent of it, is disclosed by determining the degree to which they multiply.

Whilst engineers must give close attention to the nature of the pollution of a water in advising as to its adoption for dietetic purposes, it must not be forgotten that nature comes in aid of science in remedying many of the evils which are created by the carelessness or selfishness of man. If it were not for the natural purification which rivers are capable of, the constant discharge of polluting matter into them would have made the evil cumulative. Fortunately the innumerable minute organisms which exist in rivers and which thrive on organic matter, act as scavengers. They are aided by minute plants, which, under the influence of light, liberate oxygen and help to oxygenate the water. Both these are acting to destroy the fermenting process under circumstances favourable to success, inasmuch as polluting germs from concentrated warm sewage must be at a disadvantage when in a diluted state, and in a colder fluid than that in which they commenced their existence. Although some rivers are in this way able to a certain extent to partially remedy the evils attendant on their abuse, I trust that the continuance of such abuse will be rendered impossible by stringent legislation. The investigations of Mr. Warington, of Rothampstead, with respect to "nitrification," have resulted in showing that the purifying action of the soil upon sewage is more in the nature of a biological than of a chemical or mechanical influence, as was previously thought. He has shown that a minute organism of the bacteria family (which is created by and thrives on organic refuse) exercises functions

on congenial soils by converting the polluted matter into nitrates which they secrete in the soil. The depth of their operations does not appear to extend below two feet from the surface, but the result of the change that they produce is to fertilise plant life, and to increase the purifying efficiency of land. These facts require to be known to engineers engaged in sewage disposal, as it would seem that the draining of sewaged land need not be carried out to a much greater depth than two feet, except for the purpose of serving as a mechanical filter to prevent the sewage passing too soon to the underdrains. Dr. Munroe, of Downton Agricultural College, has examined with great skill the formation and destruction of nitrates and nitrites in river and well-waters. There are many ferments in the earth which pass through it into wells and rivers from which our drinking water is obtained. The nitric ferment is one of these which appears to be least influenced by filtration, and to be readily roused to activity when it comes in contact with organic matter, such as is derived from sewage when destructive fermentation takes place. The presence of nitrogen as nitrite or nitrate in potable water has always been sought for by chemists in water analysis, and the presence of either to any extent raises a suspicion as to the character of the water. The fact of the nitric ferment becoming active in the presence of organic impurity, and the resultant destructive fermentation, suggests the inference that analysis in this direction would fail to give a reliable result either as to the permanent goodness or badness of the water under consideration. The "previous history" of the water is an essential matter which should be known to the analyst, and I think without it erroneous deductions are possible if the ordinary analysis only is made.

The decomposition of impure matter in fluids is due to the fermenting action referred to, and in some conditions it appears not to be affected by mere mechanical filtration through a layer of sand or of earth not containing the nitric ferment. This has a practical value for engineers, both with regard to sewage disposal and water supply. In the former, by requiring them to study intelligently the nature of the land which is to be used for sewage purposes, and in the latter, by adopting expedients for purifying doubtful water which suggest themselves under the light of recent chemical research. In this connection experience has proved the possibility of purifying foul water by passing it through a layer of coarsely granular iron, by which a most beneficial result on the organic matters in solution is produced and the fermenting process is arrested. I arrived at a similar conclusion some years ago in carrying out sewage precipitation operations. I found that the

addition of protosulphate of iron intensified the action of the precipitants, and destroyed (or so far as could be judged, arrested indefinitely) the activity of the ferments, which had previously led to decomposition of the organic matter and the attendant liberation of offensive gases. It has occurred to me that the effect of arresting putrefaction in sewage sludge (however desirable on sanitary grounds), may involve a diminution of its manurial effect on land, and that this may account for the difference that exists between the theoretical value which is assigned by chemists and the actual value recognised by agriculturists.

I wish to say a few words upon a subject which comes under the head of sanitary engineering, although not of the heroic order of works. The fact of the individual house not affording an opening for the expenditure of large sums of money should not prevent an interest being taken by members of this Society in what has so direct a bearing upon health. An evil which needs a very drastic remedy is in respect to the letting or selling of unhealthy houses. A tenant or purchaser should, before accepting an agreement or lease of a house, require a certificate to be given him as to its sanitary condition, which is quite as essential and important as any examination with reference to its structural safety. It is an offence, by Act of Parliament, to sell food which is unfit for consumption and which is a danger to health. In like manner I maintain that it should be made an offence to sell or let a house when in an insanitary condition, it being equally dangerous to health. Public officers should be appointed to inspect and certify the fitness of a house for occupation, and to testify to the sanitary soundness of houses. I do not consider that any agents of private (and necessarily commercial) companies are the best authorities to whom to relegate these important functions. We have public analysts, inspectors of nuisances, inspectors under the Food and Drugs Act. These are all public officers with ample powers for discharging their duties. To these should be added a body of house inspectors to keep a watchful eye on house sanitation. I would mention that an effort was made last session to meet the points I have referred to, as a Bill was prepared and presented to the House of Commons, backed by Mr. Dixon Hartland and Sir Edmund Lechmere, called "A Bill for the better Sanitation of Houses in the Metropolis."

The creation of a Minister of Health has long been talked of and experience yearly strengthens my conviction that a department solely charged with matters relating to health is imperatively required.

The Americans have set us a good example in New York

State, by making it a penal offence for bad plumbing to be done. Considering that the health and happiness of a family depend so largely upon the sound and skilful execution of the numerous works that come into the hands of plumbers, and believing, as I do, that one-half of the houses in occupation are permanently causing illness and suffering from the fact of jerry builders and jerry plumbers not being sufficiently reached and punished by the present state of the law, I should welcome some efficacious means being provided by the legislature to deal with the ignorant and unscrupulous classes through whose instrumentality thousands every year go prematurely to their graves, and many more thousands are every year enfeebled in health.

I refer to sanitary evils under a strong conviction that it is a duty to do so, and I think that every one should raise his voice to influence the public, by which alone the amazing ignorance and apathy that so largely prevail can be overcome. The legislature attends to matters which are forced on it by public opinion, and when a cry is raised by a sufficiently influential body of political men (although they may be mere faddists) how soon is that voice listened to and obeyed! When it is remembered that the death-rate for England and Wales from zymotic diseases, which averaged 4·52 per 1000 in the decade 1841–50, was reduced to 2·71 per 1000 in the decade 1880–84, some notion can be formed of the enormous sacrifice of life that has been avoided by even the partial efforts that have been already made; but much remains to be done, and none can help so much as the engineers who are engaged in works relating to improved water supply, sewerage, or otherwise, which result in saving life, in improving health, and in lessening suffering.

Gentlemen, I have referred to a variety of subjects, all of which I trust will commend themselves to your minds, as they promise ample scope for the exercise of the skill and energy of an engineer. I have far from exhausted the list, but even those which I have laid before you justify the expression of my conviction that members of our profession will find in the future abundant opportunity for the successful employment of the talents which have been committed to them. The senior members may confidently look forward to the continued and profitable exercise of their riper experience for the remainder of their professional courses, and the junior members may unhesitatingly pursue their labours in fitting themselves to succeed to the bright inheritance which will in due course be theirs. To both the senior and junior members alike I wish God speed in their respective careers.

March 7th, 1887.

HENRY ROBINSON, PRESIDENT, IN THE CHAIR.

BRIDGE FLOORS; THEIR DESIGN, STRENGTH, AND COST.

BY EDMUND OLANDER, A.M. INST. C.E.

FOR the purpose of obtaining correct data for a comparison of the relative values of particular details of engineering construction, and for selecting the best methods, at the least cost, analytical investigations are requisite. The various materials and forms, used in the construction of floors for railway and road bridges,—like other sections of statical engineering—have of late become developed by the introduction of new methods. It is therefore essential to analyse with care the several types, so that their values may be correctly realised and data obtained, with the view of facilitating the work of the designer of this class of construction.

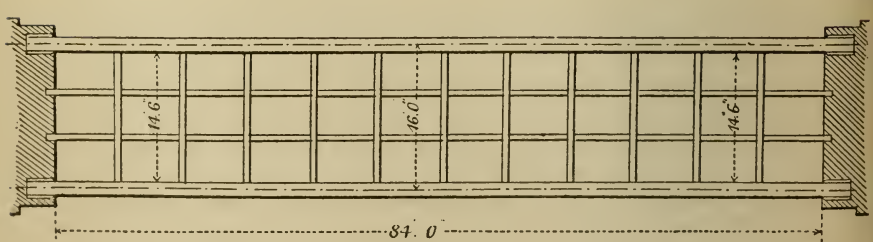
The author, having been engaged for many years in the restoration of old and in the construction of new bridges, has been frequently called upon to express opinions on various designs of floors, as to weight, strength, and cost; but cost having been the chief consideration, he has invariably had recourse to the framing of comparative estimates, before submitting an opinion; and even then the comparisons simply applied to two or three examples, clearly showing the impossibility of arriving at satisfactory conclusions, without being in possession of the most detailed information as to all the various types. He therefore considered the subject of sufficient importance to justify him in making a systematic compilation of all necessary data, and having found that the subject has not hitherto been specially treated, and the materials for arranging this paper being at hand (having been collected during a fairly long career), he submits the results of his endeavours, with the hope that the information may prove useful as a reference paper to those who may be engaged on constructive works of a similar kind.

About twenty-five years ago it was the custom of the officers of the Board of Trade, when testing the strength of

bridges, to accept a moving load of one ton, or one ton and a half (as the case might be), per foot run of single line, without particular regard to the span of the bridge, distance apart of cross girders, or the wheel base of the engine; which loads were allowed to be taken as spread over the platform and absorbed with the dead load, in assigning to the cross girders the load they had to sustain: in other words, concentrated or wheel loads on a cross girder do not appear to have been recognised. In course of time, however, a new rule was established, viz. that each cross girder of a railway bridge should be designed to support the dead load, added to the maximum weights applied by the wheels of the locomotive, at two points for a single, and four points for a double line of railway, whatever distance the cross girders might be apart. In a cross-girder flooring, the above data afforded all that was necessary for determining the strength required.

The weights concentrated at the wheel points of an engine differ on the various railways, but in taking the wheel bases and weights of the engines of the Great Western Railway, no departure from principle will arise in the details of this paper, as more or less weight must affect strength and cost in relative proportion. One of the heaviest goods tank engines of this railway weighs 48 tons, viz. 8 tons 6 cwt. on each leading wheel, and 8 tons 8 cwt. on each driving wheel. A broad gauge passenger engine gives 8 tons on each driving wheel. These may be taken as the maximum. Hence 8 tons is assumed at points directly over axis of cross girder, at each rail 5 feet apart narrow gauge.

In making the following comparisons of weight, strength and cost, a bridge of 84 feet span is assumed, to carry a single line of railway (see Plan). The main girders 16 feet apart centre



to centre; the upper booms 1 foot 6 inches wide, giving a clear way of 14 feet 6 inches, which leaves 4 feet $10\frac{3}{4}$ inches from the running edge of rail to the inside of main girders.

Floors for Single Line of Railway.

A flooring which was very extensively adopted by the late Mr. Isambard K. Brunel consisted of baulks of timber 8 inches in depth, and about 12 inches in width, laid close together and resting on the lower flanges of the main girders. In many instances the timbers were drawn tightly together by 1-inch tie rods, to form panels for distributing concentrated loads (see design A, Plate I.) on to the adjoining timbers. The span of the timbers may be taken at 15 feet 8 inches; deducting the width of gauge, there remains 5 feet 4 inches at each end.

To arrive at the strength of this floor, the length of distribution assumed is the distance between the engine wheels, taken at an average of 7 feet. The live load being 8 tons at each of two points, and the dead load 3 tons distributed. The moment of resistance of 1 foot width of beam, by 8 inches in depth = 128 (see drawing), and of seven such beams = 896. With the above loads the timber would receive a pressure per square inch:—

$$\text{Live load } P = \frac{W\,l}{M} = \frac{8 \times 64}{896} = \cdot 57 \text{ ton.}$$

$$\text{Dead load } P = \frac{W\,L}{8\,M} = \frac{3 \times 15'\,8'' \times 12''}{8 \times 896} = \cdot 08 \text{ „}$$

Pressure per square inch = ·65 „

Considering this to be the safe pressure, and multiplying by six, we get a breaking pressure of 3·9 tons per square inch, which implies that the old constant of $3\frac{1}{2}$ to 4 tons may have been taken in the calculations of strength, when these bridges were constructed. If the constant given in Mr. B. Baker's book on beams, viz. 2 tons per square inch, be adopted as the average strength of pine, the length between the bearings must be decreased from 15 feet 8 inches to 10 feet 6 inches to bring the working strain down to one-third of a ton, or one-sixth of the breaking weight, that being taken as the factor of safety. These timber floors have done good duty, and, from careful inspection, there is evidence of attention having been bestowed in the selection of sound, well-seasoned timber; for were it otherwise, the moving load would cause considerable deflections, more especially when the tie rods are omitted, as is sometimes the case, and also when the longitudinal sleepers and permanent way become flexible by wear and tear. This timber

platform does not offer a strong means of connection to the stiffeners of main girders, as the constant vibration of bolts in wood loosens the connections, and a jangling takes place after a few years' traffic.

The total weight of this flooring, for a bridge of 84 feet span, including permanent way and 3 inches of ballast, is 37·28 tons. The cost, omitting permanent way and ballast, is 184*l*. Further details are given in the comparative summary at the end of the Paper. Adopting one-third of a ton as a safe working strain per square inch, and the standard span of 15 feet 8 inches between bearings, timbers of 10 inches, or 2 inches deeper than the preceding (see estimate A[1]) and 9 tons at rail points, which will include both live and dead loads; the moment of resistance of one baulk = 200, and in 7 feet = 1400. Then $P = \frac{W\,l}{M} = \frac{9 \times 64}{1400} = \cdot 411$ of a ton, or slightly over what is allowed. This increase of strength, by an additional 2 inches of depth, necessarily augments the weight and cost. Thus the total weight of the floor is raised to 41·68 tons. The cost, omitting permanent way and ballast, becomes 224*l*.

The floor shown in design B is a full-size part section of a rough and ready mode of construction. It is made up of a series of sections known as "Barlow rails," and although they have been used, and are even now to a small extent, as permanent way, they are also utilised for the floors of bridges, but it will be seen that this use cannot be recommended. The depth is small, the moment of resistance low, considering the weight per square foot, which precludes its use for any but small spans. Placing these sections under a working strain of 5 tons per square inch, the length should not exceed 11 feet, when used for a single line of railway. Assuming the span of 15 feet 8 inches, as applied to the previous example, the live load as before, and the dead load = 6 tons, the moment of resistance of one section = 10·08, and of seven sections = 70·56, the pressure on the inch =

$$\text{From the live load } \frac{W\,l}{M} = \frac{8 \times 64}{70 \cdot 56} = 7 \cdot 25 \text{ tons.}$$

$$\text{From the dead load } \frac{W\,L}{8\,M} = \frac{6 \times 15'\,8'' \times 12}{8 \times 70 \cdot 56} = 2 \cdot 00 \text{ ,,}$$

$$9 \cdot 25 \text{ ,,}$$

Hence, in applying these Barlow rails where the main girders are 16 feet between centres, the iron is strained to 9¼ tons

per square inch. When it is considered that the Barlow rail is a girder whose depth is $\frac{1}{37}$ of the span, there can be no doubt of its weakness. There are other objections; firstly, in respect to its non-continuity, as, each section being side by side without connection, a wave deflection takes place along the floor when the engine passes over. To obviate this, it has been found necessary to connect the sections by riveting flat bars on the under side, which of course reduces the strength. Secondly: on account of the clumped ends of the sections, it is difficult to secure them to the main girders for stiffening efficiently, especially as the sections are detached. Thirdly: the drainage passing through the concrete, which is generally laid in the valleys, under the ballast as shown, passes through between the 12-inch sections, carrying with it the carbonate of lime, and forming innumerable stalactites, all over the soffit of the bridge. The total weight of this floor is 70 tons. The total cost, omitting permanent way and ballast, is 207*l.*

An old method of constructing the flooring of bridges, which, even at the present time, is occasionally adopted, is shown by design C. The cross girders are placed 4 feet apart, and are 1 foot 6 inches in depth; on their upper surface 4-inch planks are bolted longitudinally, then the usual cross sleepers, chairs and rails. The sleepers are laid symmetrically 12 inches on each side of the cross girders in order to distribute the load uniformly. In this example the live and dead loads have been taken as = 8·64 tons localised at each wheel point. The cross girders are made sufficiently strong to take these loads according to the prescribed rules of the Board of Trade. Each girder weighs 12 cwt. 16 lb. The 4-inch planking must therefore be more or less strained, according to the distance apart of the cross girders; and as the planking is usually covered with ballast, which of course promotes decay, the woodwork represents the weakest portion of the superstructure.

Treating the sleeper as a distributing beam (viz. 9 feet × 10 inches × 5 inches) the loads being at two points, 2 feet 6 inches each side of centre, = 8 tons, there remains 2 feet at each end. The moment of resistance of a sleeper of the above dimensions = 41·66; l at each end = 24 inches. As an independent beam with the above loads, the wood will be strained thus: $P = \frac{W l}{M} = \frac{8 \times 24}{41 \cdot 66} = 4 \cdot 60$ tons per square inch. The above pressure shows that the sleeper cannot be considered a perfect distributing girder. Assuming, however, for the moment that it does distribute efficiently, it will be well to know to what extent the planks are strained. Placing the wheel load directly over the chair, it may be added to the dead load, as

taken for obtaining the strength of cross girder, making together 8·64 tons; and as only one wheel can lie between the cross girders at a time, three-fourths of the load must go to the nearest cross girders $= \frac{8 \cdot 64 \times 3}{4} = 6 \cdot 48$ tons. The moment of resistance of a 12-inch × 4-inch plank = 32, and assuming the cross sleeper to distribute over four and a half of these, the total moment = 144. Hence pressure per square inch in 4-inch planking =

$$P = \frac{W l}{M} = \frac{6 \cdot 48 \times 12''}{144} = \cdot 54 \text{ of a ton.}$$

Should the cross sleepers be placed unsymmetrically, or irrespective of the position of cross girders, one of the former might lie exactly in the centre of the 4 feet opening, in which case the increase of pressure per square inch =

$$P = \frac{W L}{4 M} = \frac{8 \cdot 64 \times 48}{4 \times 144} = \cdot 72 \text{ of a ton.}$$

The foregoing calculations show that the cross sleeper, taken as an independent beam, with the wheel weights thereon, is strained beyond its breaking strength. It is true that the weights have been taken as impinging directly at the points, without being reduced or relieved—as they certainly must be to some extent—from the rigidity of the rail being sufficient to distribute the load over three or even four sleepers; at the same time, the strain has been shown to be too excessive to admit of assumed auxiliaries. The 4-inch planking, strained to ·54 and ·72 ton per inch respectively, is much stronger; but, although these strains agree fairly well with constants and factors of safety, of old date, there is evidence of too much weakness to satisfy engineers of this time, especially when dealing with moving loads. The 4-inch planks must follow the greater deflections of the sleepers, straining certain planks more than others, and giving much greater results than shown in the previous calculations. The total weight of this floor is 40·48 tons. The cost = 240*l*. The woodwork, which costs 80*l*., must be renewed every twelve or fifteen years.

A similar method of flooring, where the cross girders are of the same strength, weight, and distance apart, but support an iron instead of a timber platform, is shown by design D. In this example, longitudinal instead of cross sleepers are used. The moment of resistance of a sleeper 14 inches × 7 inches = 114.

Both loads concentrated at wheel points at the centre of the opening = 8·75 tons, the sleeper then becoming subjected to a pressure on the square inch =

$$P = \frac{W L}{4 M} = \frac{8 \cdot 75 \times 4 \times 12}{4 \times 114} = \cdot 92 \text{ of a ton.}$$

Here again the pressure agrees with what was once permissible, but which would now be considered an evidence of weakness, were it not that the sleeper receives much assistance from reliable auxiliaries. There is the timber itself, which has been calculated as a discontinuous beam of 4 feet span, whereas it may be considered continuous. Then, there is an additional girder in the permanent way rail, which, being bolted to the sleeper, may also be taken as continuous; and lastly, the wrought-iron arched floor plates that abut against the sides of the sleepers, and are finished off by 3-inch × 3-inch × $\frac{3}{8}$-inch angle irons, with one side riveted to the floor plates, the other bolted to the sleeper, supply another source of strength. The travelling loads are therefore safely carried over the spaces between the cross girders, and as the latter have been designed to support a working load of 5 tons on the inch, it may be said that this floor is of sufficient strength at all points with every prospect of permanency. The platform itself is made of arched plates $\frac{5}{16}$ inch thick with a versed sine of 3 inches. In the cross section of the bridge, they join or abut against each other, along the centre of the cross girders; while longitudinally, there are no cover or lap joints of any kind. The 3 feet 10 inches space, between the longitudinal sleepers, is filled up with one plate, finished with angle irons, and attached to the sleepers as shown. The 4 feet 11 inches between the outer side of sleeper and the web of main girder, is also finished off in the same manner; so that the edges of plates abut against the sides of the sleepers, or the webs of main girders, the latter having angle irons riveted thereon, to take the plates. Comparing this floor with the previous example C, it will be seen that the cost is increased by 37*l.* due to the substitution of iron for wood. This floor when riveted up cannot be said to be waterproof; although at the outset it might pass as such. The author has constructed a fair number of bridges of this design, and the result of his experience, as to their watertight qualities, goes to show that a constant and heavy traffic will, after a short time, open up the joints; and in this case, leakage would occur on the upper surface of the cross girders; and although it has been stopped for a time by covering the plates with a $\frac{3}{4}$-inch layer of asphalte, the water, in spite of these

precautions, in time penetrates through. The total weight of floor is 47·85 tons, and cost 277*l.*

The movable loads, produced by the wheels of an engine, are taken in this investigation at intervals of 7 feet, as an average length. A design that has been adopted in railway practice to a considerable extent, in which the cross girders are about 7 feet apart, is exemplified in detail by design E. Under the circumstances of the intervals of the wheels and cross girders being similar, the latter are equally strained, in whatever the position the wheels may be. There is no ambiguity whatever as to the distribution, or its exact direction, as the longitudinal sleeper which receives the rail, rests on 4-inch planks, that lie transversely on the wrought-iron rail bearers 12 inches deep; hence both live and dead loads must be conveyed directly to the gauge points on the cross girders. In this example the dead and live loads are taken together at 9 tons concentrated at each gauge point on the cross girder. The timber floor receives no transverse strain from the moving load, being simply a platform to support ballast and act as packing between the under side of sleepers and the upper surface of rail bearers; the latter are flush with the upper surfaces of the cross girders, so that the planking can be freely carried across the network of girders, to the webs of the main girders, where there are angle irons riveted, to take the ends of the planks. It is possible to make the planks of this floor fairly watertight by careful caulking, similarly to the deck of a ship or yacht, but it is scarcely ever done. This type of floor must not therefore be considered sufficiently waterproof when such requirement becomes imperative, as is often the case in bridges passing over thoroughfares in proximity to important and populous towns. The total weight of this floor is 37·34 tons, and the estimate amounts to 203*l.*

The design lettered F is a drawing giving full details of a floor, which illustrates very forcibly the difference of opinion that exists among engineers, respecting ironwork construction. The upper part of the drawing is a transverse section, showing the position of the main girder, and the full length of the cross girders. The lower view is a part longitudinal section, parallel with the main girders, giving the positions of the cross girders, rail bearers, &c. This type of floor has been and is now applied to the bridges of one of our northern lines of railway, where the rolling stock is heavy, necessitating, in the opinion of the engineer, that the working strain should be limited to $4\frac{1}{2}$ tons on the square inch. The rail bearers take their bearing on wrought-iron brackets (of two angle irons $2\frac{1}{2}$ inches × $2\frac{1}{2}$ inches × $\frac{5}{16}$ inch with a web of $\frac{1}{4}$ inch) resting on

the lower members of the cross girders. The ends of the rail bearers are riveted to both the brackets and the cross girders. In the centre of the 7 feet span, between the cross girders, there are intermediate bearers of 6 inches × 4 inches × ½ inch T iron intended for supporting the floor alone; the ends are secured to the rail bearers. All these girders, viz. cross girders, rail bearers and intermediate bearers, are constructed so that their upper surfaces form a horizontal plane, on which are laid wrought-iron flat floor plates ½ inch thick. These plates are joined together and made one complete platform by ½-inch cover strips 6½ inches wide, longitudinally over rail bearers, and transversely over the intermediate bearers and the cross girders, where they not only act as covers, but form part of the sectional area of the upper flange. The ½-inch thick platform is covered with a mixture of broken stone chippings, and asphalte, on top of which is a coating of pure asphalte 1 inch thick, the whole occupying 4 inches. It is supposed that the asphalte, being of a yielding nature, allows for expansion and contraction of the iron plates, and will therefore not open or crack, to allow water to pass through. On the asphalte is the ballast, which is composed of ashes, carried up to the level of the upper surface of rails; and as 3 inches is allowed underneath the sleeper for packing, the depth of ballast is 1 foot 3 inches on the top of the asphalte. The permanent way lies directly over the rail bearers and cross girders, consequently the floor plates, although ½ inch in thickness, have no other transverse strains to encounter than those produced by the weight of the stone chippings, asphalte and cinder ballast.

The great weight of this floor may be anticipated from the foregoing description. In comparison with example D, already described, which is of similar design, and has a wrought-iron platform, with the same number of cross girders and rail bearers and intended to answer the same purpose, it will be seen that the total weights, respectively, are 47·85 and 118·32 tons; and the cost is raised from 277*l.* in the one case to 442*l.* in the other. The author is unable to explain the reason for this extravagant mode of construction which appears to answer no particular purpose. It cannot be said that there are any special advantages in the design to justify the unusual expenditure of material. It is certainly a very heavy floor, and must be rendered more so in seasons of rain, from the sponge-like nature of the ballast, which must act as a kind of cistern, holding the rain water in suspension for some considerable time, on top of the asphalte, until it is slowly drained away.

A method of flooring (see design G), where the cross girders

are placed at intervals of 14 feet, or equal to about the span of two wheels of an engine, is one specially adapted to lattice or triangulated girder bridges, of a somewhat larger span than is taken as the basis of these calculations. In this instance the cross girders are 2 feet in depth, the rail bearers 1 foot 9 inches. The elevation of the former, with every detail, is shown under the larger view, to a small scale; and the elevation of the latter is also shown broken at the centre. This, with the other detailed drawings, is submitted with the object of facilitating this kind of construction, when such details are required for a floor, 16 feet between centres of the main girders. It will be found to meet the requirements of the Board of Trade. It is instructive to compare the designs C, E, and G, as detailed in the comparative summary. It will thus be seen that, while the weights of each cross girder are increasing, being respectively 12 cwt. 0 qrs. 16 lb., 12 cwt. 1 qr. 16 lb., and 17 cwt. 0 qrs. 18 lb., the total weight of ironwork diminishes as 12·34, 9·62, and 8·64 tons, and with it the cost of flooring, showing that the system of cross girders at 4 feet centres is the most expensive.

As the next design is one that introduces the modern system of flooring bridges, involving a variety of considerations and some conflicting points, in consequence of varied ideas in details of construction, the author considers it necessary to enter into a minute analysis of all the sections of new floors exhibited on that drawing.

Modern Bridge Floors.

The section of engineering which relates to the construction of bridges, has been invaded within recent years by a new and successful system of flooring. The demand for its application to bridges at the present time, which seems to be a steadily increasing one, indicates that it is not only very favourably received as an improvement by engineers, but that it probably may in the future displace the older methods. There are many kinds, whose sections are of various profiles, numbered 1 to 10 on the following figures, which are $\frac{1}{6}$th full size sections, transverse to the flooring and parallel with the main girders. Several of these floors are manufactured from well-known angle and channel sections; others are made up from stamped or corrugated plates; and some from specially designed rolled sections, for which patents have been secured.

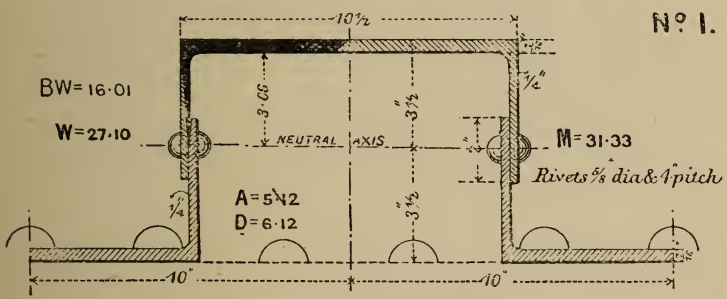
It has been the author's province to deal with these floors, in their application for the restoration of worn out and in the

construction of new bridges, which has led him to examine their respective values as regard strength and cost, adopting the method of analytical comparison.

It will be seen that some have been huddled together, as it were, without due regard to points of construction, or consideration for the work they are intended to perform. Many of these floors are now being introduced into engineering works, not only for bridges, but for floors of buildings, or otherwise, where heavy weights have to be supported. It is therefore the more desirable to inquire into the merit and demerit of each section, so that intending users may be supplied with adequate data. Directing attention, in the first instance, to sectional strength, it will be seen, by inspection of the figures, that the values of the various sections have been obtained graphically, thus enabling the relative values to be recognised by ocular demonstration.

Sections 1 to 9 have been carefully reduced to one common weight per square foot of actual area covered, or as nearly so as practicable. They are also of one depth, viz. 7 inches, and symmetrically formed, excepting No. 9, above and below the neutral axis; and they are therefore reversible. The black parts represent the inertia areas, the values of which are given, as well as the effective depths to the centre of gravity of the areas.

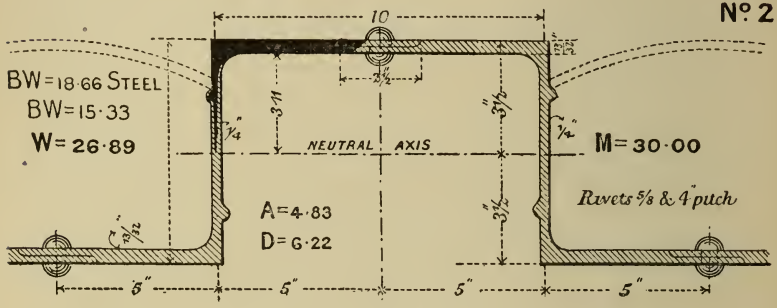
It should be explained that section No. 1 is not a manu-

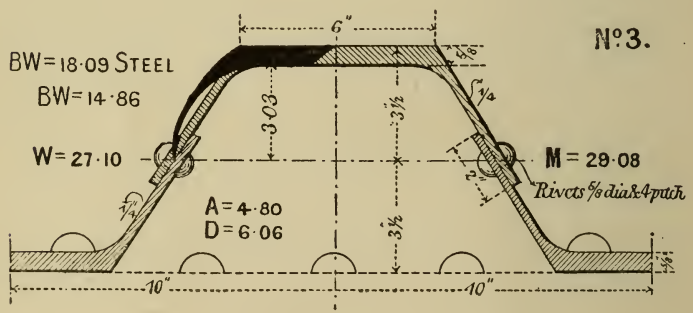


factured floor, but is an ideal profile, which the author has introduced with the intention of showing that it is one giving the greatest moment of resistance. It is, however, so far "manufactured" as to be composed of channel sections; and although the example has sides so thin, as probably to preclude it from being obtained among the usual market sections, it is nevertheless stronger than the others at the same weight per

foot. It is made up of channel sections $10\frac{1}{2}$ inches × 4 inches, the top and bottom members $\frac{7}{16}$ inch, and the sides $\frac{1}{4}$ inch in thickness. The effective depth and area are 6·12 and 5·12 respectively, for a sectional length of 1 foot 8 inches, which give a moment of resistance of 31·33. It stands first in regard to strength, which is the outcome of the greater width of flanges, at a maximum distance from the neutral axis.

No. 2 is manufactured from specially rolled sections, which



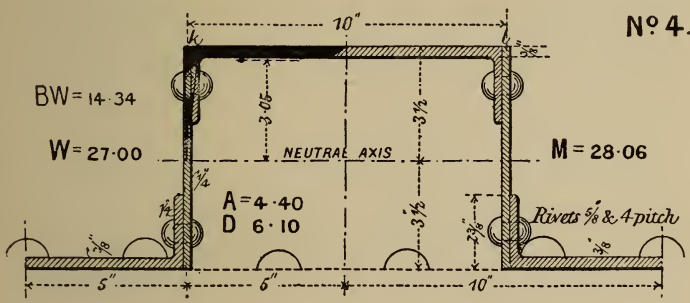


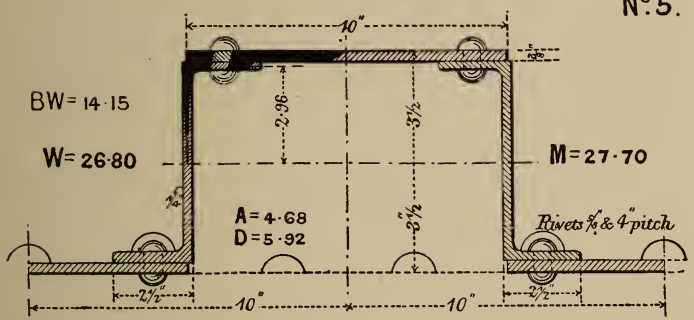
are riveted together at the centres of the top and bottom flanges, without disturbing the continuity of the surfaces by means of lap joints. The flanges are $\frac{13}{32}$ inch, and the sides $\frac{1}{4}$ inch thick. Small lugs are rolled on the webs for the purpose of receiving loose curved plates, in lieu of concrete or ballast. This section gives a high moment of resistance, and although the flange is pierced by a rivet hole, the reduction is scarcely appreciable. As a manufactured floor it stands first in point of strength.

No. 3 is manufactured of specially rolled, splayed channel

sections; the upper and lower flanges being $\frac{5}{8}$ inch and the sides $\frac{1}{4}$ inch. Comparing this with profile No. 1 it is manifest why there should be a less amount of resistance, although in both the vital members are unaffected by rivet holes, and both are jointed at the line of neutral axis; the conical form of the section reduces the width of flanges, and consequently the area, to 3·75 square inches, while No. 1 claims 4·60 square inches.

Nos. 4 and 5 are built sections, the former of channels $9\frac{3}{4}$ inches

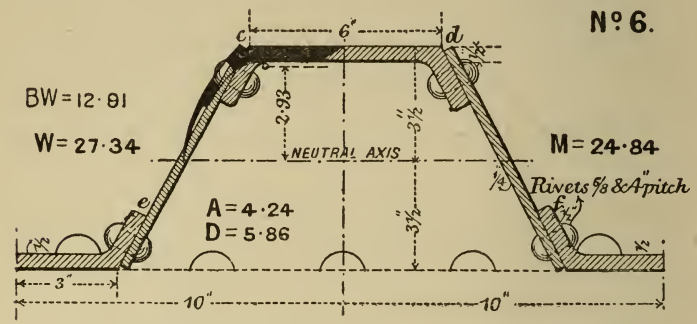


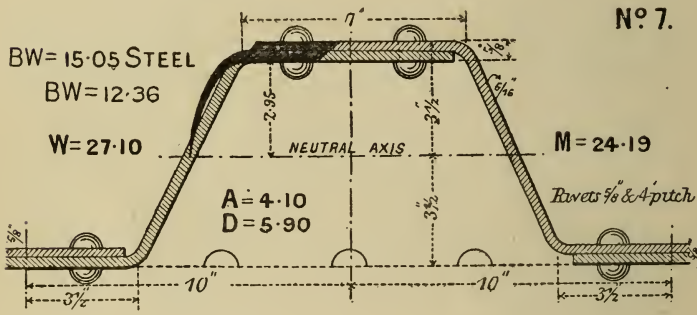


× $2\frac{3}{8}$ inches with table $\frac{3}{8}$ inch thick, and web plates $\frac{1}{4}$ inch thick. The latter, of top and bottom plates 10 inch by $\frac{3}{8}$ inch, united by Z irons $\frac{1}{4}$ inch thick. Both these floors are somewhat similar to No. 1, but the moments are reduced,—in No. 4, by the piercing of rivet holes at the top and bottom of sides; and in No. 5, by two holes at most vital points in the section.

Profile No. 6, like No. 3, is formed of splayed channel

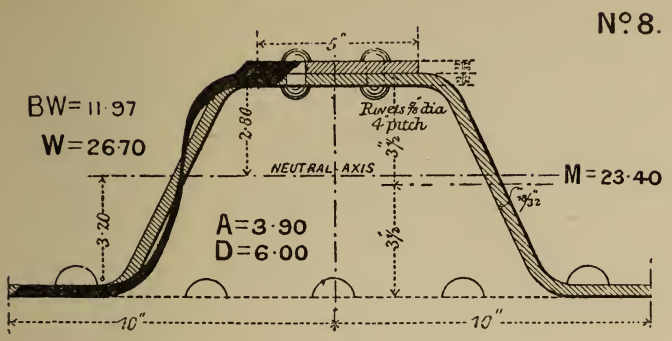
sections joined by diagonal webs, but although of similar outline, its strength is reduced by the position of the rivet holes.

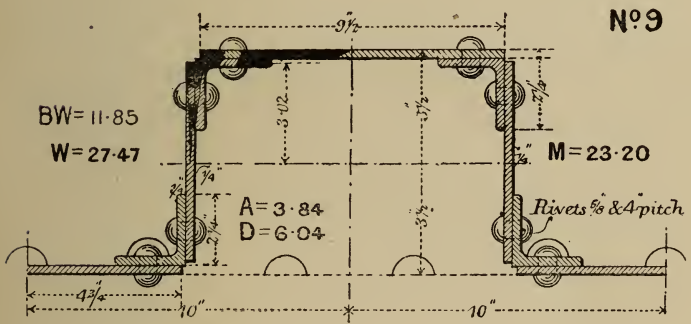


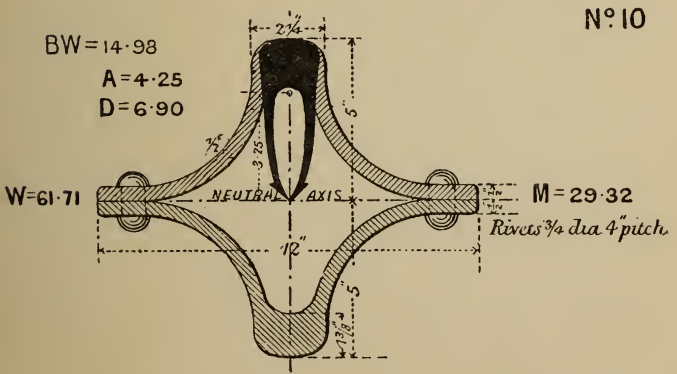


A floor of similar strength and of simple construction is shown by profile No. 7. It is composed of stamped plates, of uniform thickness of $\frac{5}{16}$ inch; they are of splayed Z forms, while the necessary and increased flange area is obtained by doubling the plate, and constructing a kind of lap joint at top and bottom. Here again strength is low, by the deduction of holes for rivets from a part of the section least able to spare the loss.

No. 8 is of special manufacture, of corrugated stamped plates. It is of uniform section throughout, $\frac{13}{32}$ of an inch in thickness, jointed at top only by a plate of the same thickness, 5 inches in width. It possesses one of the lowest moments of resistance; for, although only ·40 of a lb. less in weight than No. 1, the moment has descended from 31·33 to 23·40. The graphical area shows that the effective depth is reduced by the theoretically faulty distribution of thickness.


No. 8.
BW = 11·97
W = 26·70
Rivets ⅝ dia 4 pitch
NEUTRAL AXIS
M = 23·40
A = 3·90
D = 6·00
10"
10"


No. 9
BW = 11·85
W = 27·47
M = 23·20
A = 3·84
D = 6·04
Rivets ⅝ & 4" pitch
10"
10"


No. 10
BW = 14·98
A = 4·25
D = 6·90
W = 61·71
NEUTRAL AXIS
M = 29·32
Rivets ¾ dia 4" pitch
12"

The last of the sections, analytically compared, is No. 9, a section of floor, manufactured of a great number of pieces, and much riveting. The top and bottom flange members, as well as the sides, being plates $\frac{1}{4}$ inch thick, which are secured to angle irons $2\frac{1}{4}$ inches $\times$ $2\frac{1}{4}$ inches $\times$ $\frac{1}{4}$ inch. The loss of area by the piercing of four rivet holes and the thinness of the flange plates bring the sectional strength down to 23·20.

Section 10 is not included in this analysis; it is simply shown to represent a section of floor which has been used, when the single "Barlow rail" (described under B design) has proved too weak to carry the weight of a railway over certain spans. The weight per square foot of area covered equals 61·71 lb., or more than double the weight of the other sections. The "Barlow rails" are also discontinuous, and the fitting and fixing to main girders unsatisfactory. Leaving No. 10, and directing attention to the nine sections, it will be understood by the preceding, that the relative strengths of the sections are as the difference of their moments of resistance, but to bring those differences to a more practical shape, so that their respective values may be realised, each flooring may be assumed to rest on bearings 15 feet apart, and the breaking weight placed at the centre. Assuming 23 tons as the ultimate strength of the iron.

			Tons.
No. 1	..	B. W. $= \frac{M\,S}{\frac{1}{4}\,L} = \frac{31{\cdot}33 \times 23}{45} =$	16·01
No. 2	..	„	15·33
No. 3	..	„	14·86
No. 4	..	„	14·34
No. 5	..	„	14·15
No. 6	..	„	12·69
No. 7	..	„	12·36
No. 8	..	„	11·97
No. 9	..	„	11·85

Thus profile No. 1 will support 4·16 tons at centre, or 8·32 tons distributed more than No. 9, with practically the same weight of iron per square foot, in consequence of a more scientific disposal of iron in sectional form.

Having disposed of the question of strength, it is important to note that the stride of the sections should be a multiple of the pitch of the rivets in the main girders, so that perfect attachments may be made without affecting the regularity of the pitch throughout the structure, assumed at 4 inches in these sections.

Scrutinising the nine sectional forms from a manufacturer's point of view, without which the author could not consider the analysis complete, a comparison of cost of manufacture consequent on the construction of the various forms has to be made.

To make up Nos. 1, 2, 3, and 8 two rivets are necessary to secure the flutes together, in a cross-sectional length of 1 foot 8 inches. Profiles Nos. 4, 5, 6, and 7, require four rivets for the same object; but profile No. 9 requires eight rivets. This is no unimportant matter, for it will be shown that a very considerable difference arises in cost, due to the difference of design. Supposing the pitch of the rivets to be 4 inches, 44 rivets will be necessary to fix two flutes together for a 16 feet width of bridge; hence the total number necessary to complete the flooring of a bridge:

	Rivets.
84 feet span for Profiles Nos. 1, 2, 3 and 8 =	4400
„ „ „ 4, 5, 6 „ 7 =	8800
„ „ „ 9 =	17600

This is not all, as the total number of pieces to complete the floors Nos. 1, 2, 3, 7, and 8 are 100, in Nos. 4, 5, and 6 there are 200, but in building up floor No. 9, 400 pieces must be handled and worked into shape before the flooring is completed.

To bring these designs to a precise comparison as to the cost of manufacture, the following details may be taken as correct, subject to the usual variation of cost of labour and materials. The rivets are $\frac{5}{8}$ inch diameter and 4-inch pitch, each rivet weighs ·20 of a lb. Detailed estimates may now be framed, based on the following prices for the riveting work: Punching rivet holes at 4*s.* 6*d.* per 1000. Cost of rivets 12*l.* 10*s.* per ton. The piece price for riveting sections, Nos. 1 and 3, 1*d.* each, as hand riveting. Nos. 4, 5, and 6 at $\frac{3}{4}d.$ each (hand and hydraulic riveting). Nos. 2, 7, 8, and 9 at $\frac{1}{2}d.$ (wholly hydraulic riveting).

	£	*s.*	*d.*
Sections Nos. 1 and 3	25	4	2
Sections Nos. 4, 5, and 6	41	5	0
Section No. 2	16	0	10
Section No. 7	32	1	8
Section No. 8	16	0	10
Section No. 9	64	3	8

It must not be forgotten that the sections entailing the least cost to rivet them together, may be more expensive in their original manufacture; for example, Nos. 7 and 8 are formed of corrugated plates, and are stamped and not rolled sections; or otherwise, in the specially rolled sections, the probability of manufacturers possessing those mostly approved, may place a premium on acknowledged value; or, on the other hand, there may be a monopoly, consequent on royalty or patent rights. It is, however, important to contractors competing for the manufacture of these kinds of bridge floors, to know that in riveting

the flutes together there are found to be the above differences in the cost of riveting alone, between the various sections.

Before leaving special points of construction, it is well to remember that the perfect drainage of a railway bridge floor is a matter, in some instances, of the utmost importance to engineers; since those spanning large thoroughfares, subways under railways, or railways over other railway platforms, are required to be perfectly watertight. The usual method is to attach another floor, underneath the bridge to be drained, of corrugated iron, so that all rain water passing through the superstructure may be caught and directed by inclines to the abutments, and thence into the drains. The older methods of flooring have been found defective, even when made up of riveted arched plates, because, although fairly taut at the outset, a constant and heavy traffic has always in time caused leakage. Floors made up of a number of channels or gutters are more or less waterproof. An examination of the various sections of trough floors, just analysed, will at once show where leakage is most likely to take place. It is obvious that No. 8 is a watertight floor, next to which come Nos. 1 and 3.

This new method of flooring bridges with troughs of corrugated iron or steel, forms nothing less than a consolidated slab or panel when in place, and fixed to main girders. The upper and lower surfaces of the floor offer facilities for fixing and stiffening to the main girders, as illustrated in design K (Plate 2). The plan of taking the live and the dead loads as concentrated on a cross girder, is inapplicable for these continuous floors, so that, when the author has used them, he has been obliged to take as a standard a certain number of flutes, or length along the bridge, affected by railway traffic; and, after careful consideration, he submits that the distance between engine wheels is a fair and safe gauge for fixing that standard, and for the following reasons:—1. That a longitudinal sleeper and rail together form a sufficiently reliable girder for distributing load over the troughs. 2. That the usual cross sleepers, being close to each other, also give a similar result, although not quite so effective in point of distribution. 3. That the floor itself, putting aside distribution by the aid of sleepers and rail, say, from a concentrated load on one flute, instantly conveys that load to its fellows or adjoining flutes, for an indefinite length, owing to its solid construction.

The author having had occasion some years ago to utilise the floor of which section No. 8 forms a part, the manufacturers obligingly carried out a test of strength, by applying weights at certain points as directed. This test is shown by W (Plate 2). A length of floor was laid with longitudinal sleepers and rails to

a clear span of 15 feet. Two pairs of truck wheels were placed exactly 7 feet apart, and on their axles sheets of iron were laid. The section of trough, although of the same type as No. 8, is not of the same dimensions. It is $7\frac{15}{16}$ inches deep, $\frac{7}{16}$ inch thick, and the flutes are at intervals of 12 inches instead of 10 inches, and the top covers are $\frac{7}{16}$ inch thick. This example of floor, as before explained, possesses a low moment of resistance. It has an effective area of 5·20, an effective depth of 6·85, a moment of resistance per flute of 35·60, and weighs $28\frac{1}{2}$ lb. per square foot of area covered. An assumed working load of $34\frac{1}{2}$ tons was roughly deposited on the two axles of the four wheels, the latter being at the gauge of 4 feet $8\frac{1}{2}$ inches, to represent as nearly as possible the position of the moving load. Each of the four points received $8\frac{5}{8}$ tons. The wooden bearing blocks which received the floor, rested on the ground, on which a gauge was also fixed for the purpose of recording the deflections. These are figured on the elevation, and the successive weights applied. When the load reached $34\frac{1}{2}$ tons, the deflection registered $\frac{7}{32}$ of an inch. This test is not put forward as a very conclusive one, because the author considers that the bearings had not been fixed with the solidity necessary for obtaining perfect results. The timber having been doubtless just laid on the surface of the ground, would obviously settle down to some extent with the maximum load, the registering gauge remaining unaffected would indicate a greater and necessarily a false deflection. Had the floor rested on stone bearings, set in a bed of concrete, the author is of opinion that the deflection would not have exceeded $\frac{1}{8}$ of an inch; however, as he had used this floor on several bridges for carrying railway traffic, where the spans between the main girders were about 15 feet, it was important to ascertain its behaviour under working loads.

Assuming, therefore, the rails and sleepers to distribute the loads over $3\frac{1}{2}$ flutes, or 7 feet wheel base, the maximum strain may be obtained. As the weights are symmetrically arranged it will be $\frac{W\,l}{d} = \frac{8{\cdot}625 \times 60}{6{\cdot}85} = 75{\cdot}54$ tons. The effective area of one section (2 feet) = 5·20 and $5{\cdot}20 \times 3\frac{1}{2}$ times = 18·20 inches, therefore the strain per square inch on the iron $= \frac{75{\cdot}54}{18{\cdot}20} = 4{\cdot}15$ tons. Reversing the calculations and assuming the iron to be subjected to the usual working strain of 5 tons to the inch, instead of 4·15, the weights which could be placed at wheel points would be $W = \frac{S\,M\,3\frac{1}{2}}{l} = \frac{5 \times 35{\cdot}60 \times 3\frac{1}{2}}{60} =$ 10·38 tons, or a total weight of 41·52 tons, which would have

given a slightly increased deflection. It would, therefore, appear from the foregoing, that a floor of this description, possessing a moment of resistance of about 35 in a 2-foot length, would be sufficiently strong to take the heaviest traffic of a railway, without giving an undue deflection.

The floor represented by profile No. 6 has been adopted to some considerable extent for the bridges of the Great Western Railway. The splayed channel sections, forming the upper and lower members, are manufactured at the Swindon locomotive works. The author, after having designed the floor, received instructions from the late chief engineer, Mr. W. G. Owen, to ascertain its strength. Mr. William Dean, the chief of the locomotive and carriage department, carried out the necessary arrangements. Two sections were placed under test, they are shown at X (Plate 2), and are equal to a length of 3 feet 4 inches along the centre line of bridge. The section is somewhat stronger than the No. 6 before described, in consequence of an increased thickness of web. It is 7 inches deep, the splayed channel sections are 6 inches in width on the flat and $\frac{1}{2}$ inch in thickness, and the diagonal webs $\frac{5}{16}$ inch thick. The weight per square foot of area covered is 29·70 lb., and the moment of resistance of one flute = 26·28. A weight of 6·257 tons suspended at the centre of a 14 feet opening gave a deflection of $\frac{5}{32}$ of an inch. The value of M for two sections = 52·56, therefore $\frac{W\,L}{4\,M} = S = \frac{6{\cdot}257 \times 14 \times 12}{4 \times 52{\cdot}56} = 5$ tons, which is the working strain.

Assuming four flutes, aggregating to a length of 6 feet 8 inches, to be affected by the working load or wheel base of the engine (taken hitherto at 7 feet), the moment of resistance would be 105·12. By placing a line of railway symmetrically with the centreline, on the floor, as at B B, a leverage of 4 feet 6 inches is left at each side to the bearing, the reactions are equal on each abutment. Hence, the last obtained working strain per square inch, multiplied by moment of resistance of the four sections, and divided by distance from abutment, will give the weight which may be deputed at rail points B B to produce the same deflection as the before-mentioned weight of 6·257 tons at centre. Therefore $\frac{S \times M}{l} = \frac{5 \times 105{\cdot}12}{54} = 9{\cdot}733$ tons. Thus the preceding observations and calculations show that this floor, although not one of the strongest, when placed under a full working load, deflected $\frac{5}{32}$ of an inch.

Passing on from the safe or working load, further weights were afterwards applied (roughly thrown on to the slings), ending with an ultimate destroying weight of 30·45 tons; the

respective deflections are figured on the plate. It is then quite fair to assume that four sections would break with double the weight, viz. 60·90 tons.

The moment as above given of the four sections being 105·12, the span 14 feet or 168 inches; the breaking strain per square inch $= S = \frac{WL}{M4} = \frac{60{\cdot}90 \times 168}{105{\cdot}12 \times 4} = 24{\cdot}33$ tons. That is to say, the iron being of good quality, broke when the pressure reached 24·33 tons on the square inch.

Before leaving these sections of floors, there are still some important points in construction that should not be lost sight of. Practice has shown that it is advantageous to have clear upper and lower surfaces, where the floor takes its bearing on the main girders, and also for stiffening to sides of main girders from the upper surface. See design H. Nos. 1, 3, 4, and 6 offer facilities in this respect, as there are no rivets in the top or bottom tables. Nos. 5 and 9 are free to receive the stiffeners on the upper tables, but in Nos. 2, 7 and 8 the rivets that secure the flutes together must also fix the stiffeners to main girders. It is also important that the pitch of the flutes should accommodate themselves to the pitch of the rivets in main girders, because the fitting and fixing must be executed at site. Examining Nos. 1, 2, 3, 4, 6, 7 and 8, there would appear to be no easy means of increasing or decreasing their horizontal lengths; but Nos. 5 and 9 are in a degree adjustable. In the case of a number of troughs aggregating a defect, more or less, in length, the top plates could be riveted on to any width of flute.

The author has found section No. 5 very useful, as it not only accommodates itself to the pitch of the rivets in the flanges of the main girders, but also to various strength requirements. For example, one of the same type, composed of Z sections $6\frac{1}{2}$ inches deep × $3\frac{1}{2}$ inches × $\frac{3}{8}$ inch, the upper and lower plates being also $\frac{3}{8}$ inch and 12 inches in width, has been used on several bridges.

It had a moment of 40·69, and not being found sufficiently strong for another bridge, $\frac{1}{2}$-inch flange plates were substituted, raising the moment to 48·87; and when still greater strength was found necessary, $\frac{5}{8}$-inch plates were riveted to the same Z sections which increased the moment to 55·83. This speaks well for No. 5 section, more especially as such a floor could be manufactured without infringing on specially rolled or patent sections. Certainly the flange plates of No. 9 could be similarly treated, but it has been shown, that that section is one that cannot be classed as worthy of consideration, particularly in a constructive point of view.

It should be stated that sections Nos. 3 and 7 are now

manufactured of steel as well as iron, which raises their respective strengths very considerably, viz. as much as 21·75 per cent. as shown by the figures.

The results of the preceding analysis are epitomised in the following summary:—

1. It has been shown that the strongest floor may be manufactured of channel sections.
2. The pitch of flutes, or troughs, should be a multiple of the pitch of the rivets of main girders.
3. In the manufacture of these floors, one type may cost for riveting alone one-third, while another costs only one-twelfth of a similar contract sum.
4. While only 100 pieces of iron are required to construct one kind of floor, 400 are necessary to complete another.
5. An increased cost in the manufacture of one floor over another does not necessarily mean a defective floor.
6. Simplicity of manufacture is not necessarily the most economical; as specially rolled sections may carry with them a monopoly or patent right.
7. Nos. 1, 3 and 8 are the only waterproof floors.
8. The results of the test of strength are favourable.
9. It is necessary that these floors should accommodate themselves to the pitch of the rivets in the main girders. Section No. 5 is well adapted in this respect, and can also be utilised with advantage for various strength requirements, without altering design, a property which the other sections do not possess.

Design H, Plate 2, illustrates a case where the main girders are situated below the level of the rails, and there can be no doubt that this mode of construction is the most economical. The other examples represent floors resting on the lower booms of main girders. Of course these are the most conformable to rule, and to the requirements of railway practice generally; but when headway may be ignored, as in the case of viaducts across valleys or ravines, the construction may be designed somewhat after the details exhibited. Of the ten examples it is the least in weight and cost. Ballast is omitted, because the author is desirous of showing the minimum weight of structure, which will perform the same duty, as the heavier systems already described. He would also add that he is aware of a bridge, which has a similar floor from which the drainage is carried away as perfectly as from the roof of a house; and which very shortly after a storm becomes comparatively dry again. The corrugations act as gutters, and the water being unimpaired by ballast, passes rapidly away. The floor in

question, after having been painted, received two coats of tar to prevent oxidation.

The main girders are 10 feet apart, they might be less; indeed there are numbers of bridges where they are almost under the lines of rails; but reducing this distance increases the overhanging portion outside, and such an arrangement is now understood to be objectionable. Deducting the rail gauge from the 10 feet, there remains 2 feet 6 inches on each side. The short leverage allows of a small section of floor being used. It is not exhibited, but is one of similar manufacture to that of No. 8. It is 4 inches deep; the pitch of the flutes being 1 foot 4 inches, and the thickness $\frac{5}{8}$ inch. It has a moment of resistance of 10·25 in one section of 1 foot 4 inches, and therefore 53·81 in 7 feet, which multiplied by a working strain of 5 tons to the inch = 269 inch tons, therefore $\frac{M}{l} = \frac{269}{30} = 8{\cdot}96$ tons, which the floor will safely carry. The floor is very easily fixed to the main girders, and as the latter should be braced by diagonals the structure is quite rigid. Wood packing is inserted in the valleys of the corrugations in order that the longitudinal sleepers and rails may press evenly in distributing the load. The parapet is of simple construction, an angle-iron stiffener is secured by two rivets to the top member of the floor, on its vertical face are riveted angle-iron standards, 3 inches × 3 inches × $\frac{1}{2}$ inch, and to these are fixed the longitudinal bars. The total weight of this floor, 84 feet × 14 feet 6 inches, is 16·84 tons or 30·98 lb. per square foot, and the total estimate including parapets is 153*l.* or 1·82*l.* per foot run.

The last floor in the group of Single Line Railway Bridges, is also of the corrugated type, but of a larger section than the preceding example, as the one now under consideration takes its bearings on the lower members of the main girders, but not at the lowest possible point. When headway will permit, it is desirable to let the floor take its bearing on independent angle-irons, as shown in both views by design K. This bearing may also be of channel section form, the lower member taking the place of the usual angle-iron for main girders, while the upper part receives the floor. This method of making independent seats saves a considerable amount of trouble, as the positions of the rivets for the flutes are independent of those along the lower flange of main girders. Constructed in the manner shown, the floor has a flat and uninterrupted surface to be riveted on to the angle-iron bearing as shown; at the same time it is important that the vertical joints of the main girder should coincide with the centre lines of the troughs, so that the

diagonal stiffener A may be fixed at regular intervals. The main girders in this design are 16 feet between centres, and for a bridge of the standard span. The floor is of No. 3 section, and is of steel manufacture. It has already been shown that this section has a moment of resistance of 29·08, and it will support safely 12 tons at wheel point, with a factor of safety of $\frac{1}{4 \cdot 31}$. The total weight is 20·88 tons = 34·80 lb. per super. foot, including the permanent way, and the estimate of cost is 193*l.*

The following observations embody the practical conclusions resulting from the previous analysis:—

1. The floors mostly adopted give an average weight of 36 lb. per square foot, without ballast, and the practice of recklessly using the latter not only increases cost of floor, but also of main girders.

2. The use of ballast is not only objectionable from the fact of increasing the cost of superstructure; but, lying on the wood or iron platform for years, it produces rot in the one, and oxidation in the other, which deteriorates and shortens the working life of the floor.

3. One foot of ballast, laid on the platform of a single line bridge, is equal in weight to two-thirds of the heaviest movable load, and in the case of a double line bridge, it is above half the same load. To provide for this excessive depth of ballast being supported, the weight of iron in superstructure must be increased by 20 or 25 per cent. Taking 20 per cent., the result is that a company paying for 1000 tons of iron bridge work in one year, equal to about 14,000*l.*, pays away about 2800*l.* over and above what is necessary.

4. The life of a floor would be much prolonged by draining it as completely as the roof of a building, and at the same time facilitating by constructional arrangement, at all possible parts, free access for cleaning, scraping and painting; the periodical enforcement of this class of maintenance adding to extended duty.

5. In point of economy, it is advisable in the construction of a floor to employ iron wholly, not iron and wood, or wholly wood.

6. That the best of the new methods, viz. that of iron or steel corrugated plates, is the most economical, provided that a 7 feet length of distribution, 8 inches depth of floor, 10 or 12 inches pitch of flute, and 32 or thereabouts as the moment of resistance of one section are considered sufficient to satisfy strength requirements. It is therefore necessary to revert to, and consider more fully, a subject already partially entered on.

Distribution of Movable Load on Trough Floors.

The author is aware that this question of distribution is the most debatable point about the new systems of flooring, and that it is most important to settle a "distributive length" which should be acceptable at once to engineers and to the inspecting officers of the Board of Trade. He has used in the previous calculations of strength a distributive length of 7 feet, equal to an average distance between centres of engine wheels, and he has adopted this believing it to be fully justified by the tests before described and illustrated in diagrams W and X, and by consideration of the combined elements of resistance, viz. the strength of the separate flutes of the flooring, the rigid connection between the flutes, and the distributing power of the permanent way.

On this question he will be glad to evoke, if possible, expressions of opinion from the members of this Society, and especially from officers of the Board of Trade. To facilitate this he has prepared diagrams S T U V (Plate 3), showing a flooring similar to No. 1, and the variations of section required to adapt it to different distributive lengths.

On diagram S is shown this flooring adapted to the 7 feet length. The troughs are 12 inches wide centre to centre, and 8 inches in depth. Sides or webs $\frac{1}{4}$ inch thick and upper and lower flanges $\frac{3}{8}$; moment = 38·27. The weight for the 84 feet span is 19·12 tons, and the cost, 172*l*.

The load it will sustain, at a stress of 5 tons per inch, is $W = \frac{S\,M\,3\frac{1}{2}}{l} = \frac{5 \times 38{\cdot}27 \times 3{\cdot}5}{66} = 10{\cdot}14$ tons at each of the gauge points.

If the 7 feet length be considered too great, diagram T shows the modification necessary for a distributive length of 4 feet, allowing the same working stress. The depth of troughs is 8 inches as before, but the flanges are increased to $\frac{5}{8}$ inch and the webs to $\frac{3}{8}$ inch. The total weight becomes 28 tons and the cost 275*l*.

If it were necessary to make a single trough (2 feet length of floor) strong enough to carry the load, the thicknesses will have to be largely increased, or the depth of trough altered. Diagram U exhibits one case (which is of course quite unpractical) and V the other. The weights and cost being, for U 64·62 tons and 696*l*., and for V 36·87 tons and 376*l*.

But the author appeals with confidence to the tests before referred to as practical evidence that trough floors of the

ordinary sections may be safely used for full working loads. They are marked examples of a case that often occurs in construction, when the actual strength is the result of such a combination of elements that it does not admit of exact calculation, especially when it is remembered that one cannot simply add together the resistances of the various parts, but must make allowance for the varying deflections of each element of the construction. One undeniable advantage gained by the use of these floorings is that they afford the minimum of depth of structure, and are therefore most valuable in the many cases, especially of small bridges in and near towns, where headway is limited. Cross sleepers can be sunk into the troughs, and the underside of the rail brought to within half an inch of the upper surface of the flooring.

Floors for Double Line Bridges.

Small span bridges, carrying a double line of railway, are more generally constructed with one main girder at the centre of the 6 feet way, and two outer girders. At the same time, there are numbers of bridges constructed, where only two outer girders are employed; their distance apart being about 27 feet, the floor being supported on the lower flanges.

The weights and costs given in the comparative summary and lettered C′, D′, E′, G′, are for designs corresponding to those under similar letters for single line bridges, the strength of the cross girders being, of course, increased in proportion to the increased width between main girders.

Wrought-iron and steel trough floors are shown by designs K and K² (Plate 2), the section being similar to No. 5. The depth of flooring in each case is 14 inches and the distance, centre to centre, of troughs 2 feet 8 inches. The flanges are $\frac{5}{8}$ inch thick for wrought iron and $\frac{7}{16}$ inch for steel, the webs being $\frac{3}{8}$ inch and $\frac{5}{16}$ inch respectively. The distributive distance is taken at 7 feet, as before, and the floorings are calculated to carry the moving and dead loads with working stresses of 4·93 tons per inch for iron and 6·46 for steel.

Public Road Bridges.

It is well known that the rules regulating the strength of road bridges, are not so stringently enforced as those for railways. In London, the requirements of the Metropolitan Board

of Works are—that besides the dead loads, the superstructures shall be constructed to sustain with safety a moving load of people, the ordinary vehicular traffic, and also occasionally special loads represented by road rollers, traction engines and ploughing engines. The bridges beyond the confines of Greater London do not appear to be under any technical controlling influence, in respect to their strength, more than what emanates from the individual opinions of county, borough, and road surveyors. Accepting the requirements of the Metropolitan Board of Works, it seems correct to conclude that the rules which are now in force at the Board of Trade for calculating the strength of the cross girders for railway bridge floors, are also applicable for the strength of floors of public road bridges, especially since the introduction of road rollers. The designs O, P, Q and R (Plate 4), are four examples selected for the purpose of exemplifying their difference of weight, although all are qualified to perform an equal amount of duty.

Design O is a partial longitudinal section of floor, with cross girders 1 foot 6 inches deep at intervals of 4 feet. The bridge is assumed to be the same span and width as before. The cross girders support 9-inch brick arches, whose versed sine is $6\frac{1}{2}$ inches. Concrete is laid on the arches up to the level of upper surface of girders, on which again is laid 1 foot of metalling. The lower flanges of girders are tied together by bars 3 inches $\times$ $\frac{3}{4}$ inch to receive the thrust of the arches. Each cross girder is calculated to support a road roller wheel load of 6 tons at centre, people at each side of road roller = 1 ton 2 cwt., and a dead load which includes brickwork, concrete, metalling and girder itself = 7·60 tons per bay of 4 feet. The dead loads massed together aggregate a total weight of floor of 158·85 tons, as shown in column No. 1 of the summary, or 264·70 lb. per square foot in column No. 3, which is four times as heavy as the usual railway bridge floor; but then there are 16·55 cubic yards of concrete, 38·50 cubic yards brickwork, 49·77 cubic yards metalling, and 20 cross girders. Half its total weight, viz. 79·42 tons, must be supported by one main girder, and as a moving load of people would only amount to 30 tons on the latter, the floor is two and two-thirds times as heavy as the moving load it has to sustain.

The author, having designed certain bridges of the kind above described, desired to reduce this excessive weight, whenever it was necessary to construct floors of this design, and having submitted to the late chief engineer of the Great Western Railway, Mr. W. G. Owen, a sketch of a floor of similar design, but lighter, as illustrated by the design P, he

was instructed to test the strength of an arch of 4½ inches or one brick turned in cement, on which was laid cement concrete. The girders were placed 5 feet apart as shown by the drawing Y, Plate 2.

The weight applied consisted of pig iron, cast-iron chairs, and fish-plates, which had all been previously weighed. The centre of the load coincided with the quarter span, or 1 foot 3 inches from the bearing, as a vulnerable point in the arch. The total weight reached 14 tons. It was the author's intention to destroy the model, but in consequence of the iron load pile becoming dangerous to the workmen employed, the experiment was not fully carried out. The arch sustained the above-mentioned load without any alteration of form, so that there was nothing to record, more than that, as the heaviest fore-wheel load of a 15-ton road roller is 4½ tons, the applied load was three times that weight. This test is not exhibited with the object of showing conclusive results, but is simply introduced for what it is worth. The author is of opinion, however, that a 9-inch brick arch, between cross girders 4 or 5 feet apart, is unnecessarily strong, and also, speaking in the absence of a perfect test, that 4½-inch brick arches laid in cement, covered with cement concrete, as shown on design P, will support the heaviest traffic that can be brought upon it, and with the usual margin of safety.

The floor on design Q is shown by a transverse section, and a part longitudinal section. It is composed of rolled sections of similar profile to that of No. 3. It is of steel, and has a moment of resistance of 105 inch tons in a length of 1 foot 4 inches. It is 6 inches deep, the upper and lower members ½ inch and the diagonal webs ¼ inch thick, which are secured together by ⅝-inch rivets. The troughs are filled with concrete, and to 2 inches above the upper surface of the floor, at the centre of the bridge, on which is laid 1 inch of asphalte, on the surface of which is laid wood pavement 5 inches deep.

It has been shown in that part of the previous description which refers to iron floors for railway bridges, that the new corrugated system of flooring is more economical than the older methods, in which cross girders and iron curved plates are adopted. This is verified in the case of those now under consideration. The design R illustrates a floor which has been much adopted in recent times for over-bridges. These curved plate platforms have taken the place of "Mallet's buckled plates," doubtless in consequence of their increased strength; and also forming by cover plates one complete iron covering.

The author observes in conclusion, that the various data

which have been collected, arranged and tabulated, do not only give the means of estimating the relative values of the different types of floors, as to weight and cost, for forming comparisons, but furnish means of supplying the designer with data for intended works. This is obvious on an inspection of the tabulated summaries, and in many respects the designs also, as some of the details may be extracted and copied. Work in the office may be expedited by using the various multipliers of the tables, as in the following example:—

For Parliamentary purposes the estimate of cost of a floor is required for a single line bridge of 60 feet span of type E, to four different widths of floor. No. 11 column gives the cost of floor per foot run, which multiplied by span equals total cost. Thus:—

	£	£
For 16 feet wide	2·42 × 60 feet	= 145·20
„ 15 „ „	2·31 × 60 „	= 138·60
„ 14 „ „	2·15 × 60 „	= 129·00

For 13 feet wide 1·98*l.* × 60 feet = 118*l.* Any of the dead weights therefore may be obtained from the tables to add to movable load, as data for arriving at the weight and ultimately the strains in main girders, as instanced in the following example:—

Required weight on main girder of 120 feet span of double line floor D′. The weight per foot run is 1·139 tons, therefore,

$$\frac{1{\cdot}139 \times 120}{2} = 68{\cdot}34$$

add,

Live load 1·27 ton × 120 = say	152·40
Weight of girder .. .. „	43·00
Total weight for calculating strains =	263·74 tons.

It would be unnecessary to cite further examples. It only remains to add, that by an inspection of the tabulated summaries, in connection with the designs, other information respecting weight and cost can be obtained, which may prove useful to those engaged on similar works of engineering construction.

COMPARATIVE SUMMARY

SINGLE LINE BRIDGES.		Width of Floor.	1	2	3
			Weight of Flooring including Permanent Way and Ballast.		
			Total on Bridge.	Per foot run of Bridge.	Per foot super.
		feet.	tons.	tons.	lb.
Timber baulks 8 inches deep, and cross tie girders 12 feet apart	A	16	37·28	·443	62·13
		15	35·06	·417	62·35
		14	32·83	·391	62·57
		13	30·60	·364	62·78
Timber baulks 10 inches deep, and cross tie girders 10 inches deep, 12 feet apart ..	A[1]	16	41·68	·496	69·46
		15	39·18	·466	69·65
		14	36·68	·436	69·86
		13	34·19	·407	70·14
Barlow rails, concrete and ballast	B	16	70·00	·834	116·66
		15	65·67	·781	116·74
		14	61·38	·730	116·91
		13	57·08	·679	117·10
Cross girders 4 feet apart, 4-inch planking, and cross sleepers	C	16	40·48	·482	67·50
		15	38·00	·452	67·55
		14	35·49	·422	67·60
		13	32·97	·392	67·65
Cross girders 4 feet apart, arched iron plates $\frac{5}{16}$ inch thick, and longitudinal sleepers	D	16	47·85	·569	79·75
		15	44·88	·534	79·80
		14	41·92	·499	79·85
		13	38·95	·463	79·90
Cross girders 7 feet apart, rail-bearers, 4-inch planking, and longitudinal sleepers	E	16	37·34	·444	62·23
		15	35·36	·420	62·87
		14	33·04	·393	62·94
		13	30·70	·365	62·99
Cross-girders 7 feet apart, rail-bearers, flat iron plates, asphalte, cinders and chippings	F	16	118·32	1·408	210·35
		15	110·70	1·317	210·86
		14	102·98	1·225	211·25
		13	95·08	1·132	211·30
Cross girders 14 feet apart, rail-bearers, 4-inch planking, and longitudinal sleepers	G	16	36·36	·443	60·60
		15	34·24	·407	60·87
		14	32·33	·385	61·58
		13	30·53	·363	62·62
Corrugated flooring 4 inches deep, over two main girders 10 feet apart	H	14·6	16·84	·205	30·98
		13·6	16·09	·190	31·77
		12·6	15·34	·182	32·72
		11·6	14·59	·173	33·84
Trough flooring 7 inches deep, main girders 16 feet apart, type section No. 3	K	16	20·88	·248	34·80
		15	19·86	·236	35·30
		14	18·85	·224	35·91
		13	17·83	·212	36·57

OF WEIGHT AND COST.

4	5	6	7	8	9	10	11
Total Weight of Ironwork.	Weight of one Cross Girder.	Weight of one Rail-bearer.	Weight of Iron Floor-plates.	Cubic feet of Timber.	Cubic yards of Concrete.	Total Cost.	Cost per foot run of Bridge.
tons.	tons. ct. qr. lb.	tons. ct. qr. lb.	tons.			£.	£.
1·16	0 2 3 15	..	..	896	..	184	2·18
1·11	0 2 2 24	..	..	840	..	173	2·06
1·06	0 2 2 5	..	..	784	..	163	1·93
1·01	0 2 1 15	..	..	728	..	152	1·81
1·26	0 3 0 24	..	..	1120	..	224	2·66
1·24	0 3 0 4	..	..	1050	..	211	2·51
1·21	0 2 3 12	..	..	980	..	198	2·36
1·19	0 2 2 20	..	..	910	..	185	2·20
19·20	..	..	19·20	..	13·44	207	2·46
18·00	..	..	18·00	..	12·60	194	2·31
16·80	..	..	16·80	..	11·76	181	2·15
15·60	..	..	15·60	..	10·92	168	2 00
12·34	0 12 0 16	..	..	448	..	240	2·85
11·68	0 11 2 0	..	..	420	..	227	2·70
10·34	0 10 0 17	..	..	392	..	204	2·43
9·23	0 9 0 4	..	..	364	..	185	2·20
20·85	0 12 0 16	..	8·70	..	5·31	277	3·29
19·73	0 11 2 0	..	8·24	..	4·92	262	3·12
17·91	0 10 0 17	..	7·76	..	4·53	238	2·83
16·32	0 9 0 4	..	7·28	..	4·14	217	2·58
9·62	0 12 1 16	0 2 1 10	..	448	..	203	2·42
9·30	0 11 3 6	0 2 1 10	..	420	..	194	2·31
8·64	0 10 2 13	0 2 1 10	..	392	..	181	2·15
7·93	0 9 1 8	0 2 1 10	..	364	..	167	1·98
26·97	0 15 0 24	0 3 1 10	12·00	..	..	442	5·26
25·65	0 14 0 21	0 3 1 10	11·25	..	..	418	4·97
24·23	0 12 3 25	0 3 1 10	10·50	..	..	394	4·68
22·57	0 11 3 4	0 3 1 10	9·75	..	..	369	4·40
8·64	0 17 0 18	0 7 1 1	..	448	..	191	2·27
8·17	0 15 1 4	0 7 1 1	..	420	..	180	2·14
7·91	0 14 0 27	0 7 1 1	..	392	..	171	2·04
7·56	0 12 3 12	0 7 1 1	..	364	..	162	1·93
12·60	..	..	10·87	..	..	153	1·82
11·85	..	..	10·12	..	..	144	1·71
11·10	..	..	9·37	..	..	135	1·60
10·35	..	..	8·62	..	..	126	1·50
16·78	..	..	16·26	..	..	193	2·29
15·77	..	..	15·24	..	..	181	2·15
14·75	..	..	14·22	..	..	170	2·02
13·73	..	..	13·21	..	..	158	1·88

COMPARATIVE SUMMARY

			1	2	3
		Width of Floor.	Weight of Flooring including Permanent Way and Ballast.		
			Total on Bridge.	Per foot run of Bridge.	Per foot super.
DOUBLE LINE BRIDGES.					
Cross girders 4 feet apart, 4-inch planking, and longitudinal sleepers	C[1]	feet. 27	tons. 83·64	tons. ·995	lb. 82·60
Cross girders 4 feet apart, and arched iron plating $\frac{5}{16}$ inch thick	D[1]	27	95·74	1·139	94·56
Cross girders 7 feet apart, rail-bearers, 4-inch planking, and longitudinal sleepers	E[1]	27	73·13	·870	72·22
Cross girders 14 feet apart, rail-bearers, 4-inch planking, and longitudinal sleepers	G[1]	27	70·09	·834	69·23
Wrought-iron trough floor, 14 inches deep, and 2 feet 8 inches centre to centre of troughs	K[1]	27	55·78	·664	55·09
Steel ditto, ditto, ditto	K[2]	27	44·64	·531	44·09
ROAD BRIDGES.					
Cross girders 4 feet apart, 9-inch brick arches in mortar, and concrete	O	16	158·85	1·890	264·70
Cross girders 4 feet apart, 4½-inch brick arches in cement, and concrete	P	16	121·75	1·440	202·93
Wrought-iron corrugated floor, 6 inches deep, and wood paving	Q	16	58·56	·697	97·50
Cross girders 5 feet apart, and arched iron plating $\frac{3}{8}$ inch thick	R	16	91·44	1·088	157·40
DISTRIBUTION OF LOAD.					
Flooring composed of channel section No. 1, distributive length 7 feet	S	16	19·12	·227	31·87
Flooring ditto, ditto, distributive length 4 feet	T	16	28·02	·333	46·70
Flooring ditto, ditto, distributive length 2 feet	U	16	64·62	·770	107·70
Flooring ditto, ditto (deeper), distributive length 2 feet	V	16	36·87	·439	61·45

OF WEIGHT AND COST.

4	5	6	7	8	9	10	11	12
Total Weight of Ironwork.	Weight of one Cross Girder.	Weight of Iron Floor-plates.	Cubic feet of Timber.	Cubic yards of Concrete.	Cubic yards of Brickwork.	Cubic yards of Metalling.	Total Cost.	Cost per foot run of Bridge.
tons.	t. c. q. lb.	tons.					£.	£.
35·60	1 15 1 3	..	756	..	..	..	597	7·10
49·77	1 15 1 3	14·49	..	8·80	..	..	657	7·82
25·94	1 16 3 25	..	756	..	..	..	469	5·29
22·91	2 16 3 6	..	756	..	..	..	430	5·12
47·57	..	46·57	..	..	..	..	547	6·51
36·43	..	35·43	..	..	..	..	437	5·20
12·86	0 11 3 5	..	..	16·50	38·50	49·77	241	2·87
11·24	0 10 0 22	..	..	22·00	19·44	37·33	192	2·28
16·05	..	15·00	609	12·44	..	..	239	2·84
19·44	0 10 0 0	10·61	..	8·29	..	41·48	264	3·14
15·00	..	14·50	..	..	..	..	172	2·05
23·92	..	23·40	..	..	..	..	275	3·27
60·52	..	60·00	..	..	..	..	696	8·28
32·77	..	32·75	..	..	..	..	377	4·48

DISCUSSION.

The PRESIDENT said that he was sure the meeting would agree with him that the paper was a most interesting one. As a record of data it was of the highest value, coming as it did from one of the most experienced men living in such matters. He believed that it would be of great service both to engineers and to architects. He had never met with a paper more lucidly written or more admirably illustrated.

Mr. A. T. WALMISLEY agreed that the profession would set great store upon such a collection of information. The paper put the facts before them in a very practical way. He was glad that Mr. Olander did not recommend all the trough sections he had shown, because some of those sections were very undesirable. Price is regulated by the shape of the section, which should be as simple as possible and each bar a duplicate of the other. He thought that the splayed sections were decidedly preferable to those formed with a right angle, unless they were constructed as shown in No. 9. The question of riveting was very important. Some of the sections were made after the pattern of ordinary corrugated iron, but flat on the ridges, so as to enable the connection with other parts of the structure to be made with more than one rivet. The use of mild steel was gradually coming into the practice of engineers, and therefore the author's references to that material were very valuable. As to the question of patents, he (Mr. Walmisley) thought that if an engineer found a design suitable he would not reject it because it was a patent and necessitated a little extra cost. Messrs. Lindsey and Co. have made a trough flooring $5\frac{1}{2}$ inches deep, consisting of splayed channel irons riveted together at the neutral axis, thus forming troughs $4\frac{1}{2}$ inches wide on the flat heads of the ridges, and $9\frac{1}{2}$ inches in the opening, the heads being $\frac{5}{16}$th inch and the sides $\frac{3}{16}$th inch in thickness. These were independently tested, when a single trough was found to deflect $\frac{9}{16}$th inch with a load of 9 tons applied on the bottom of the trough in the centre of a span of 10 feet, 1 inch with a load of 12 tons, and to yield without fracture under a load of 15 tons. Four troughs of the same section riveted together and tested on the same span of 10 feet, gave a deflection of $1\frac{1}{8}$ inch in the two central ridges with a load of $15\frac{1}{2}$ tons dead weight applied at the centre of the three valleys.

Mr. J. R. BAILLIE said that his firm had manufactured bridges of all kinds and with all kinds of floorings, and among them were floorings similar to No. 8 and to that shown in

design H. This flooring had been adopted by many railways in England and had passed the Board of Trade survey. He did not think that there was any form which would be more economical. He quite endorsed the statement of Mr. Olander that these floorings were the cheapest that could be used. They had tested flooring of No. 8 pattern, but 5 inches deep by $\frac{5}{16}$th inch thick, and they could not break it at all. It bent down to the ground under a weight of 44½ tons on one plate with a span of 12 feet. He should be very glad to show any gentleman the tests at his works.

Mr. SCHÖNHEYDER said that in analysing the strength of the timber beams in designs A and B, the author spoke of the pressure per square inch. He (Mr. Schönheyder) did not understand what that meant. He supposed the author meant a certain tension per square inch of the wood. In speaking of the stress upon the sleepers, the author did not say whether it was tensional stress or crushing stress. With reference to the tables of the different floors from A to G, the author gave the prices, but he (Mr. Schönheyder) inferred that the floors were not all of the same strength. If some were not of sufficient strength, that table of comparative prices was of small value. He would suggest that an additional column be added, giving what would be the cost of the floors if they were all brought up to sufficient strength for the work which they had to do. It was stated that in the design H the longitudinal sleepers rested not only on the upper part of the corrugations, but also on their lower part by the interposition of small blocks of wood. He should have thought that such an arrangement was hardly necessary; and it would seem to be disadvantageous as stopping the proper drainage of the floor. The spaces between the two longitudinal sleepers would form troughs, which would retain water. It was very important that all iron structures should be properly drained to prevent rust. In connection with that point he would like to ask whether the trough floors were made perfectly straight or with a camber. It seemed to him that a slight camber would facilitate drainage.

Mr. CHARLES LEAN thought that Mr. Olander had underestimated the strength of the section No. 7, for he seemed to have deducted two rivet holes at the top and two at the bottom. The rivets, however, were put in zigzag, so that only one rivet needed to be deducted at top and bottom at a given section. The test shown on diagram Y was a very important one; but he thought that Mr. Olander was under the mark with regard to the amount of load which he calculated would come on a road bridge. He had been told by Board of Trade inspectors that the heaviest traction engine which could come on a road

bridge ought to be allowed for. After making inquiries from the manufacturers of traction engines, he had himself designed bridges to carry a load of 20 tons on four wheels, of which 15 tons were on one pair of wheels. That was an extreme case, but still a possible one. Mr. Olander seemed to have omitted one point with regard to the thickness of jack arches. It was that the concrete would no doubt materially assist the single ring, and the rise of the arch being greater with a single than with a double ring, the strength of the arch was not so much reduced as it would at first sight appear to be. Of course the saving in dead load was the saving of a portion of one ring.

Mr. A. R. PENNY (representing Messrs. Lindsay & Co.) said that the use of any of the trough floors mentioned in the paper was mainly governed, first, by comparative cost, and then by strength and weight. There was great difficulty in rolling channel irons with very deep fins, especially if these were required to be so thin as some of those shown. The maximum depth of fin yet obtained was 4 inches, and then the thickness had to be the same as that of the table. Floors relying upon deep channels would be almost out of the market. As compared with experiment W, he had lately tested some flooring on a span of 20 feet, the depth of the sections being 7 inches, as in W, and the material mild steel. On $4\frac{1}{2}$ inches in the centre of the span a load of 30 tons was hung, giving a deflection of $\frac{3}{8}$ of an inch, as against 2·75 inches. The speaker's firm were now making trough floors of mild steel, because, with a considerably less weight per foot, and consequently reduced load on the main girders, it gave a greater initial strength, at a comparatively small increase of cost. In reply to the President, he said that the thinnest channel his firm had been able to roll was $\frac{3}{8}$ of an inch in the fin, with a maximum depth of 4 inches. In reply to Mr. Schönheyder the speaker added that the section used in the test referred to consisted of two flutes, made up of what they should call four troughs—two upper and two lower, one of the lower being complete and the other divided into halves, making a section similar in every respect to that shown in experiment W.

Mr. J. H. CUNNINGHAM said he thought that traction engines and road rollers did not strain bridges so severely as might be supposed, because their wheels were very wide and distributed the great loads that they carried.

Mr. JOHN BARKER said that Mr. Schönheyder had suggested that some floors might be the better for a little camber. This reminded him that some years ago he was concerned with a bridge to be sent abroad, the floor of which was made without either cross or longitudinal girders. It consisted of corrugated

plates, laid transversely to the line of the bridge. They were $6\frac{1}{2}$ inches deep × $\frac{5}{16}$ of an inch thick, and about 1 foot 7 inches pitch, with a camber of $\frac{7}{8}$ inch, the ends resting on the inner sides of the bottom flanges of the main girders and abutting against the webs. A piece of this flooring about 16 feet × 11 feet 3 inches was tested by him with a load of 55 tons, equal to 6 cwt. per square foot. The deflection was $\frac{27}{32}$ of an inch and there was no permanent set. As the ends of the plates did not abut against anything and were not fastened down, the conditions of the test were much more unfavourable than those of a floor as actually constructed. If he remembered rightly, the clear span of the flooring was 16 feet. He had no doubt that the resistance of the floor would be increased by the camber when the ends abutted against the main girders. He believed that many road bridges would answer their purpose and be much cheaper if built entirely without cross girders and with trough floors having a camber. This mode of construction would both provide for drainage and give the maximum headway. He was much pleased with Mr. Olander's paper, and believed that he could appreciate it, because he had given a great deal of attention to specifying, designing and inspecting bridges, for many years past. The paper contained the results of a great deal of plodding work which nobody could thoroughly appreciate except those who had had to perform similar work. It seemed to him a pity that more bridges were not built without ballast and without so much timber in the floors. In many of the bridges with which he had been concerned in India, the floors consisted of a grid made of flat bars about 6 inches wide and $\frac{1}{4}$ or $\frac{1}{16}$ of an inch thick, with as large a space between the bars as possible compatible with convenience in walking on the floor. A floor so made allowed the water to pass freely through, and it was possible to get at it for thorough examination and painting. If a flood rose beneath such a bridge, it would not lift it; nor would such a floor offer any resistance to the wind. He believed Sir John Hawkshaw had had a case in which a bridge with solid timber floor was lifted by a tornado and carried off its bearings. The "ideal" trough section (No. 1) which Mr. Olander had shown might, as he stated, be the section which would give the greatest moment of resistance, but, as a former speaker had said, it would be a very difficult section to roll, in fact, he did not think that it could be rolled at all, as it was drawn.

Mr. J. W. Wilson, jun., said that he recognised the Barlow section again with great pleasure. The manifold uses to which that section had from time to time been put would make a subject for a paper. He had seen it used for columns, beams,

struts, and even for almost the entire framework of a pier, and now it appeared again as a bridge-floor. He had often heard that one of the special advantages of the Lindsay section was that the line of rivets was approximately on the neutral axis. He should like to ask the author to what extent this was the case. There was a section not shown by the author and which was in some measure a prototype of those mentioned. It was introduced and used some years ago by Mr. J. Dowson, a contracting engineer, with whom he had been associated. Its original object was the construction of piles or columns, for which purpose four of the sections were riveted together through flanges rolled on them. These columns were introduced in the first instance for pier work, but it was found that, owing to their thinness, they soon perished in the sea water. The section was, however, subsequently used for the flooring of an ordinary road; being laid alternately up and down and riveted together through their flanges, in which position they made a good stiff flooring. Such a paper as that which had been read was one which needed thinking over. He thought that much credit was due to those who, like the author, would take the trouble to embody in such a paper their practical experience, whereby a valuable condensation of important matter was secured for the use and guidance of the profession.

Mr. H. A. CUTLER said, he noticed that the trough floors shown were very shallow in proportion to their length. In many bridge floors which had failed it had been observed that the failure was due to such shallowness, rather than to the unit stress in the iron being more than was usually allowed. He wished to ask the author whether he had found that these floors were stiff under the vibration of heavy and fast moving loads, or whether he thought they were open to the same objection as shallow floors of ordinary construction.

Mr. LEONARD GILL said that it appeared to him that it would be utterly impossible to rivet sections which had vertical webs riveted at the centre of their depth, such as section No. 1, as there was no room to get a strike at the rivet. He urged that section No. 2 had no power of transmitting any part of its load to the next flute without the means of a longitudinal girder, as it was entirely dependent on the rivet heads in the top and bottom of the flutes for doing such work. As to section No. 3, the fins were not always rolled exactly to the correct thickness: he had laid 5000 square feet of that floor and had considerable difficulty with it on that account. In Design K, Mr. Olander had suggested the putting of a shelf angle-iron above the main angle-iron in the bottom flange, with the object of not being bound by the pitch of the rivets of the

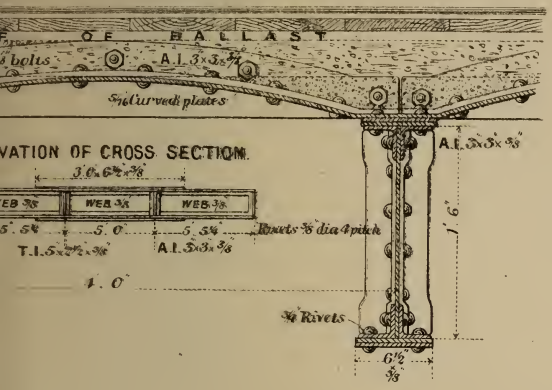
main girder. He did not see that the shelf angle-iron would obviate that, for the main angle-iron riveting determined the position of the stiffeners, and as they must be riveted with the shelf angle-iron to the web of the main girder, the position of the flooring was as much fixed in relation to the main girder as if it were riveted directly to the lower flange.

Mr. C. J. LIGHT expressed his entire agreement with what had been said as to the value of the paper. But he thought that the author should be asked to give them the price of the materials upon which he had based his calculations, in order to complete the information which was put before them. The author took 16 feet from centre to centre of main girders as the basis of his work; but said that he calculated the length of bearing of the floor as 15 feet 8 inches. He supposed that the author justified this by the fact that the cross girders and the flooring generally had to rest upon the angle-irons of the main girders. He believed, however, that the more usual practice of taking the distance from centre to centre as the basis of calculation for the flooring was far better, because the deflection of the flooring produced, or had a tendency to produce, a lateral twist of the main girder. Although the taking of the centre to centre distance as the span did not obviate this evil, at least it very considerably reduced it. He had himself tried some years ago the 4½-inch or one-brick arch in road bridges, and with very great advantage. He knew cases in which the 4½-inch arches had been used for road bridges near an iron manufacturing town, where there was very heavy traffic, and they had stood for years without the slightest sign of yielding. He believed that it was a better construction, both economically and scientifically, than the 9-inch arch.

Mr. OLANDER, in replying to the discussion, said that the various profiles of trough floors were simply numbered in the paper, but he had obtained the permission of the President to give the names of the manufacturers. Section No. 1 was an ideal and theoretical section which he had introduced for comparison with the others, and was not intended as a practical one, though it might be made so by increasing the thickness. No. 2 was a patented section belonging to Mr. John Ellis, late inspector of ironwork for the Great Western Railway, but rolled in steel and manufactured by the Bolton (Lancashire) Iron and Steel Company. Mr. W. H. Lindsay, of South Wharf, Paddington, owned the patented section No. 3, which is also rolled in steel. No. 4 had not been much adopted or made special by any particular firm. No. 5 was a section manufactured by Messrs. Finch and Co., of Chepstow. It was a very good bridge floor, although pierced by rivets in the top and

bottom tables, and, as he had stated in the paper, accommodated itself to different strength requirements, and to irregularities of pitch in fixing. No. 6 section had been adopted to a considerable extent on the Great Western Railway, and was manufactured at the Swindon works, but it was a weak and otherwise unsatisfactory flooring. No. 7 was manufactured in steel and iron by Messrs. Braithwaite and Kirk of West Bromwich. He had deducted two rivets, as Mr. Lean had remarked, because he was under the impression that they ran in line. Of course if they were zigzag he would give the section the benefit of deducting one rivet hole instead of two. Messrs. Westwood, Baillie and Co. were the owners and manufacturers of section No. 8. It had a low moment of resistance, owing to the metal being of uniform thickness, but he had used it on several bridges and found it to be a good floor and easy of erection. No. 9, as he said in the paper, was not worthy of consideration.

With reference to these modern floors he should wish to state that he had been quite impartial all through the analysis, as he had written the paper for the advantage of his own office, and for others in the profession who might hereafter refer to it. Great care had been exercised in obtaining correct inertia areas for sections Nos. 1 to 9, and reliable moments of resistance. Mr. Baillie stated that he had put 50 tons on a piece of flooring to test it; but if the number of troughs tested was the same as in W (Plate 2) that weight would be little more than an ordinary working load. In reply to Mr. Schönheyder's question as to what he meant by pressure on the square inch, he referred to pressure produced by transverse strain, treating the section in the same manner as he would a girder, when subjecting the effective area, and necessarily the extreme fibres, to a working strain of 5, or breaking strain of 20 to 22 tons. He had noticed an observation that had often been made with respect to these new floors, viz. that the rivets were weak, or the line of rivets the weakest portion, that is to say, that the rivets connecting the flutes together would be much punished by a travelling load. But this was not the case. The severest strains came upon the top or bottom tables; as might be shown by taking a rolling load of 12 tons distributed by sleeper and rail over four troughs, or say 7 feet. The obliqueness of the sides would increase the shearing strain to about $14\frac{1}{2}$ tons. Assuming the floor to have a full span of 16 feet for single line of railway, the length from wheel point to bearing would be 5 feet 6 inches, in which length No. 16 rivets $\frac{5}{8}$ inch diameter, would be necessary; whereas in the four troughs there would be eight rows, or No. 128 rivets at 4 inches pitch, having an

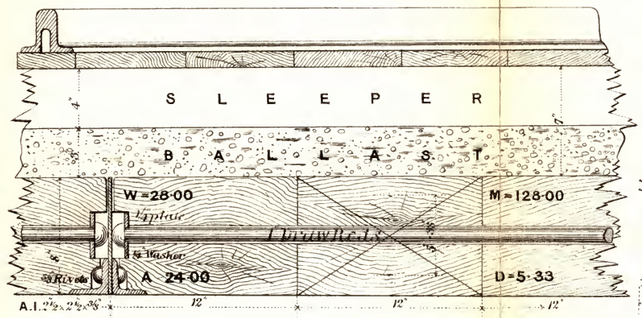

OF BALLAST
bolts
A.L. 3×3×¾
⅝ Curved plates
VATION OF CROSS SECTION.
3'0"×6½"×⅜"
EB ⅜
WEB ⅜
WEB ⅜
5'. 5¾"
5'. 0"
5'. 5¾"
Rivets ⅞ dia 4 pitch
T.I. 5×2½"×⅜"
A.L. 3×3×⅜
1'. 0"
A.L. 3×3×⅜
1'. 6"
¾ Rivets
6½"
⅜

APART.

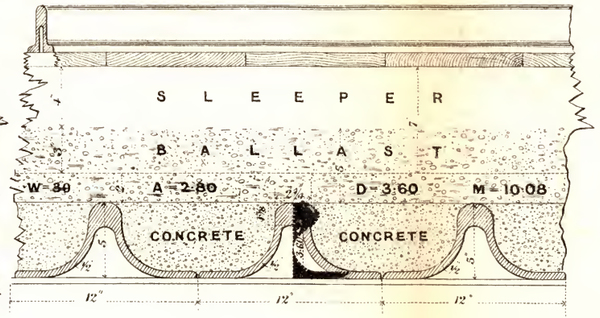
R
S T
ANKING
3×3×⅜
ARER
¾ Rivets
2'. 0"
2 plates 9×⅜"
¾ Rivets
9"

DER.

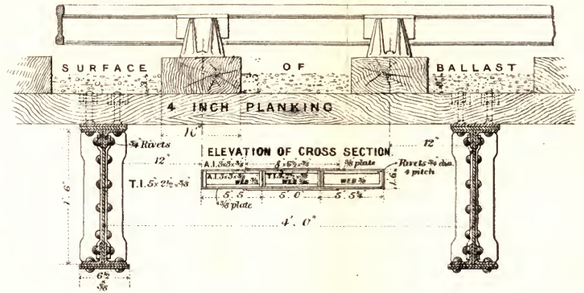
A



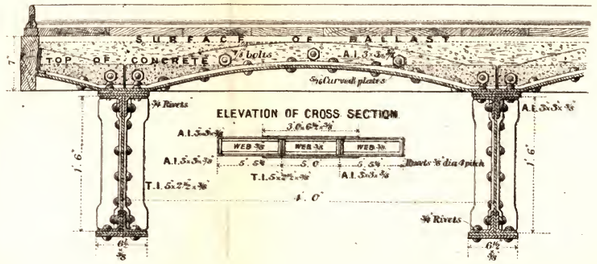
B



C

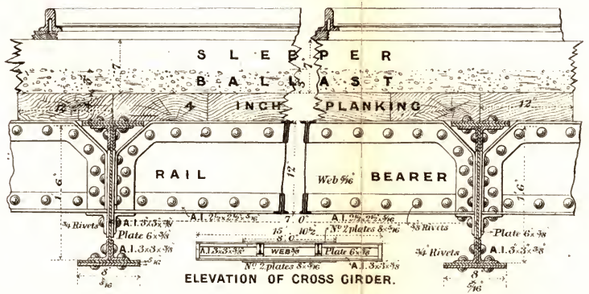


D



E

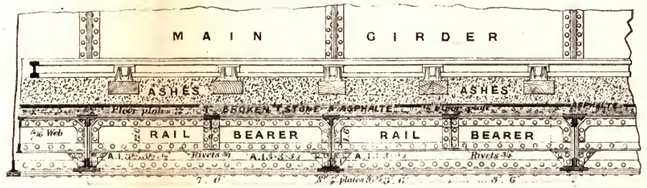
LONGITUDINAL SECTION.



F

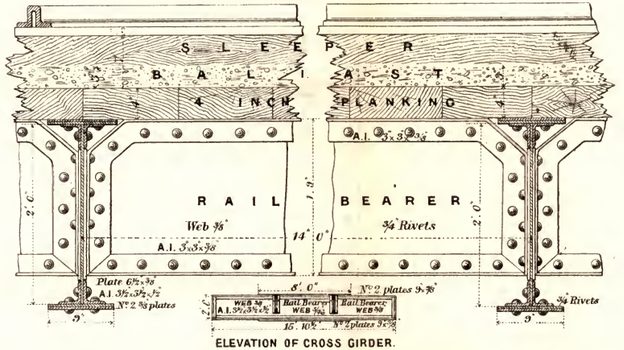
TRANSVERSE SECTION.

LONGITUDINAL SECTION.



G

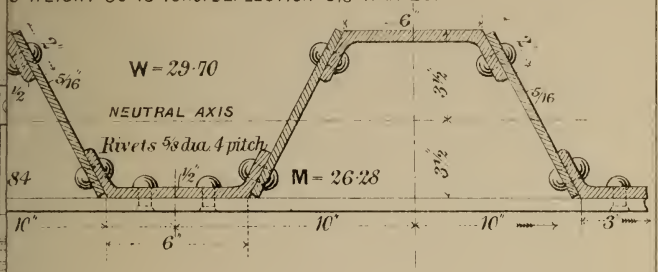
CROSS GIRDERS 14 FT APART.

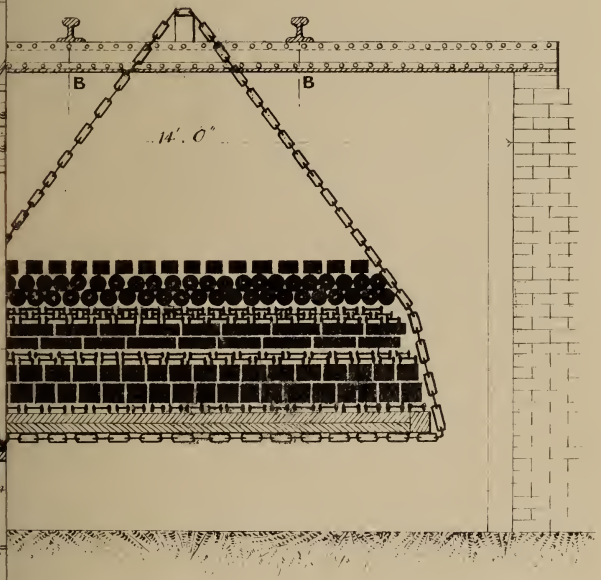


F. & F.N. Spon, London & New York.

'EST OF FLOORING Nº 6.

G WEIGHT 30·45 TONS. DEFLECTION 3 13/16 INCHES.

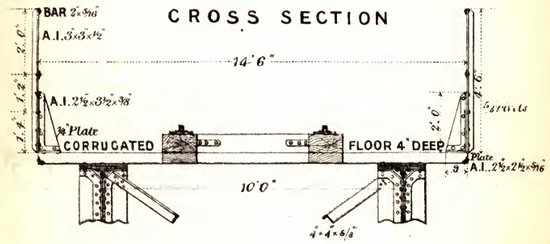




TONS	DEFLECTION
14·40	9/16 INCH
20·72	1 1/16 "
22·87	1 1/4 "
25·76	1 11/16 "
27·50	2 INCHES

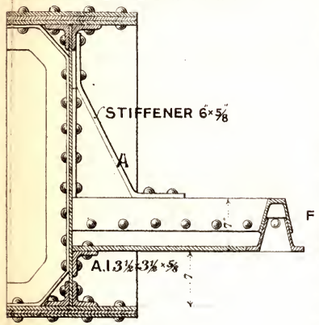
H

CROSS SECTION

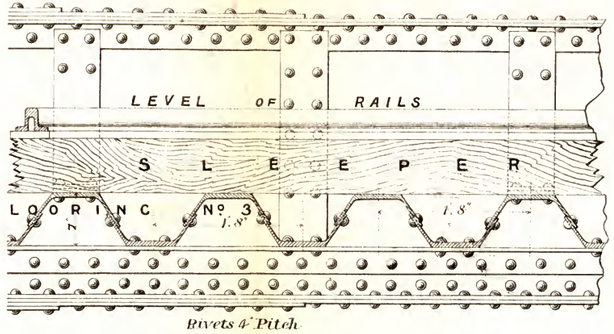


K

CROSS SECTION

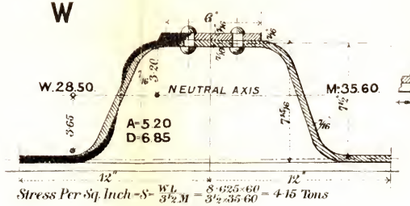


LONGITUDINAL SECTION



Rivets 4" Pitch

W

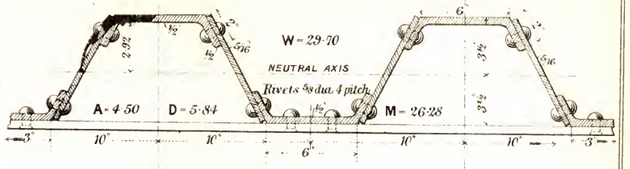


Stress Per Sq. Inch = $S = \frac{W_L}{3\frac{1}{2}M} = \frac{8 \cdot 425 \times 60}{3\frac{1}{2} \times 35 \cdot 60} = 4 \cdot 15$ Tons

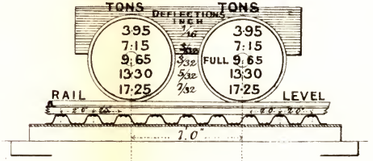
X

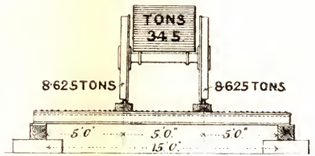
TEST OF FLOORING Nº 6.

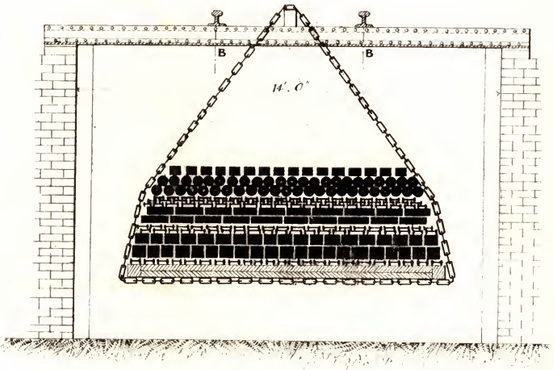
BREAKING WEIGHT 30·45 TONS DEFLECTION 3⅛ INCHES.



TEST OF FLOORING Nº 8.



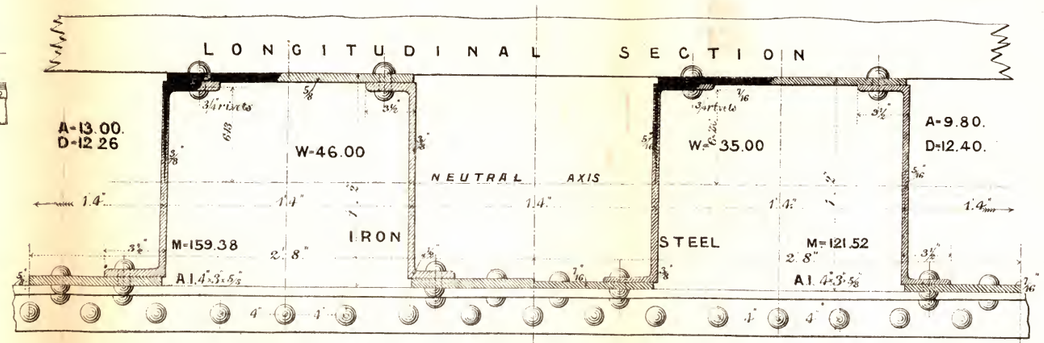




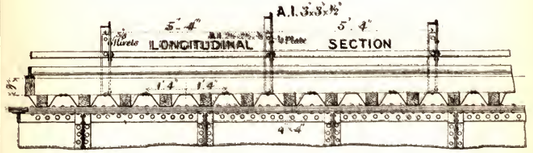
TONS	DEFLECTION.	TONS	DEFLECTION
2·00	— 1/64 INCH	14·40	— 9/16 INCH
3·70	— ⅛ "	20·72	— 1 1/16 "
6·25	— 5/32 "	22·87	— 1¼ "
7·00	— ¼ "	25·76	— 1 11/16 "
8·94	— ⅜ "	27·50	— 2 INCHES

K¹

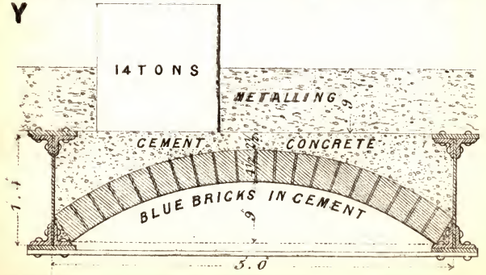
LONGITUDINAL SECTION



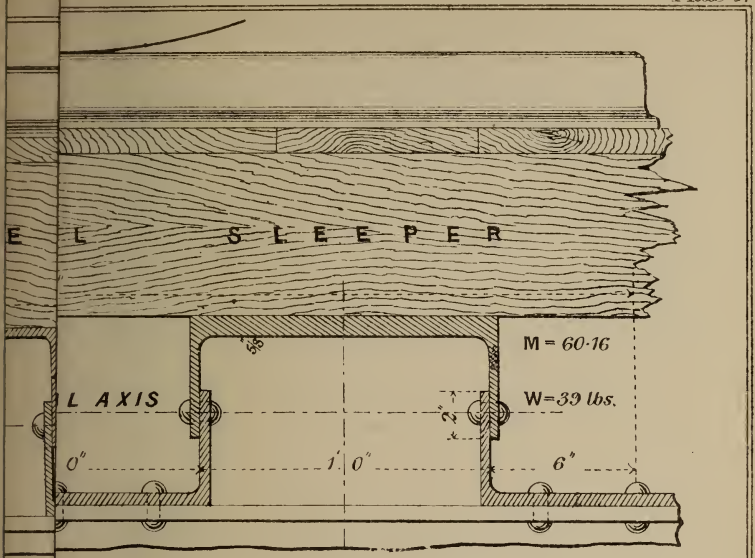
K²



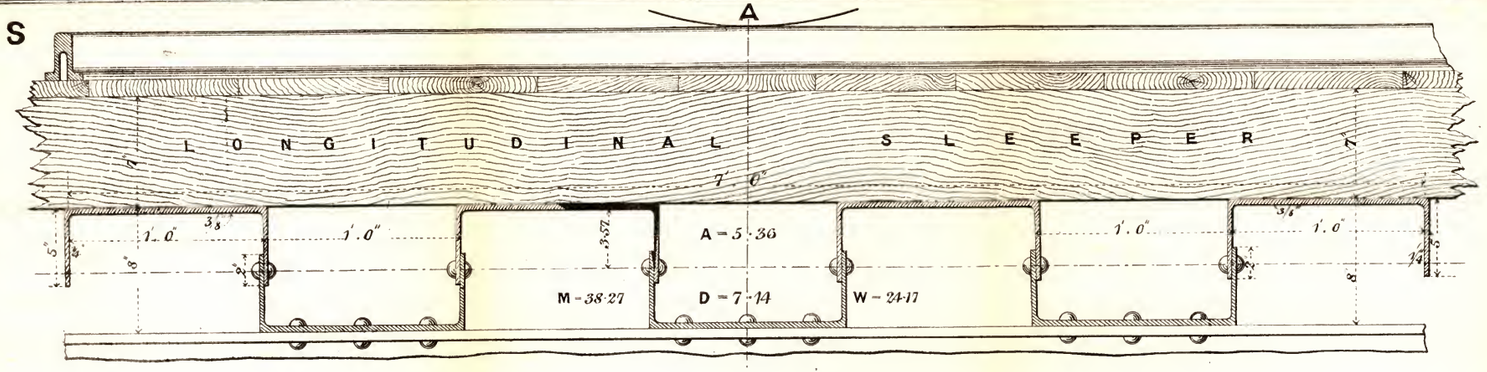
Y



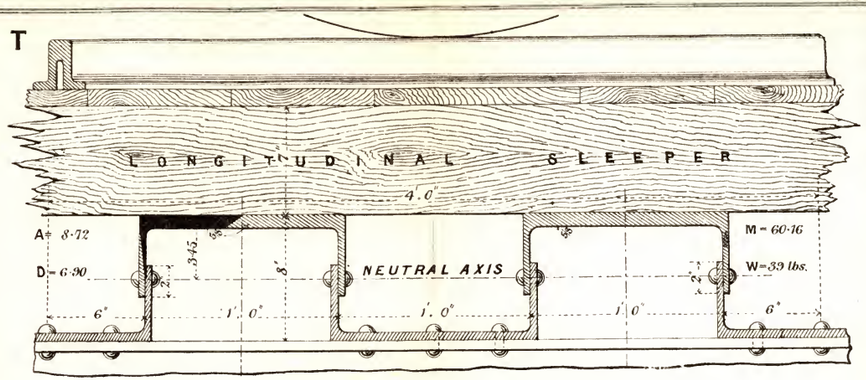
E & F N Spon, London, & New York.


E L SLEEPER
M = 60·16
W=39 lbs.
L AXIS
0"
1' 0"
6"

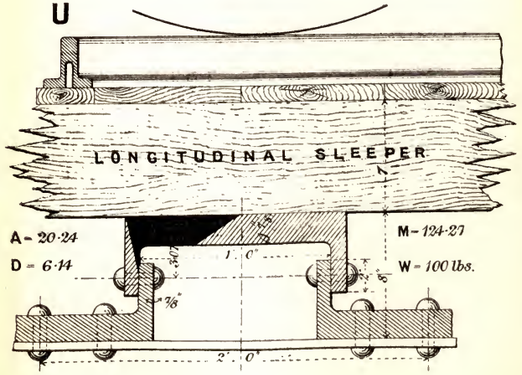
S



T

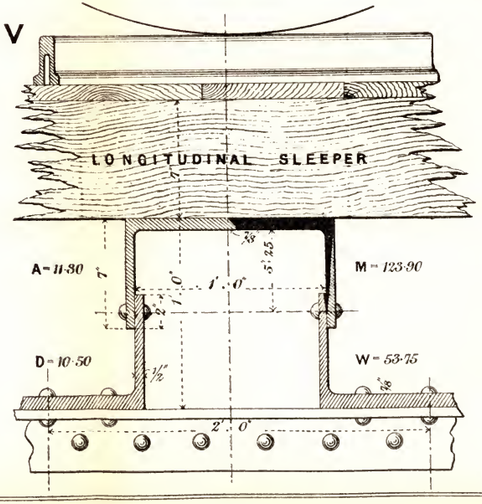


U



Scale 1½ = 1 Foot

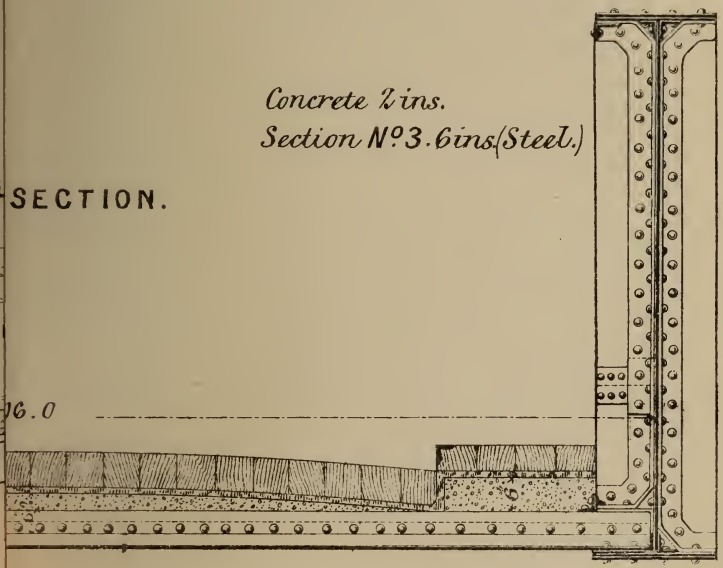
V



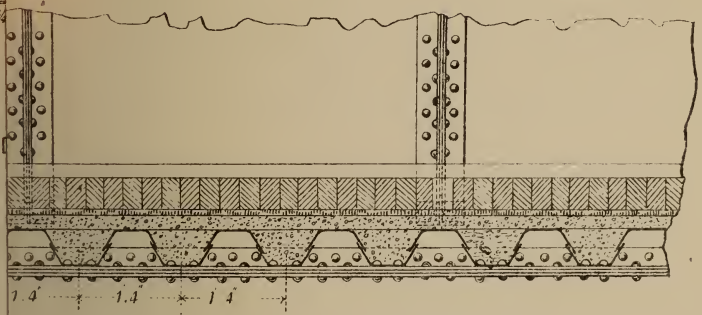
E & F.N. Spon, London & New York.

Concrete 7 ins.
Section No 3. 6 ins (Steel.)

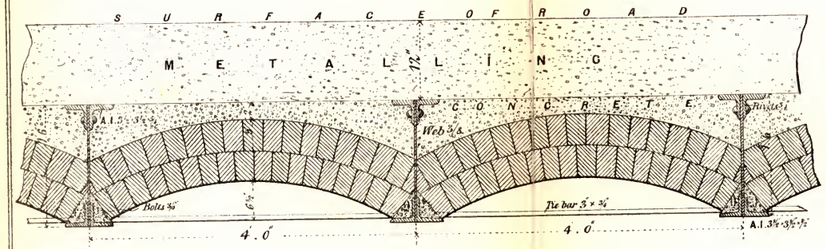
SECTION.



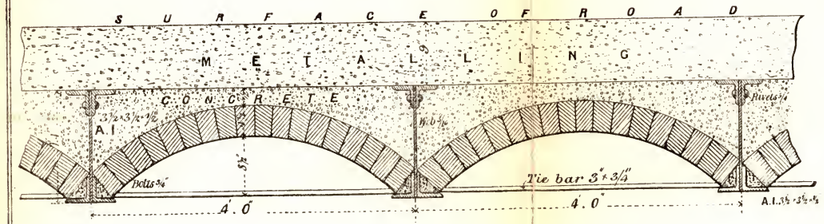
NAL SECTION.



O

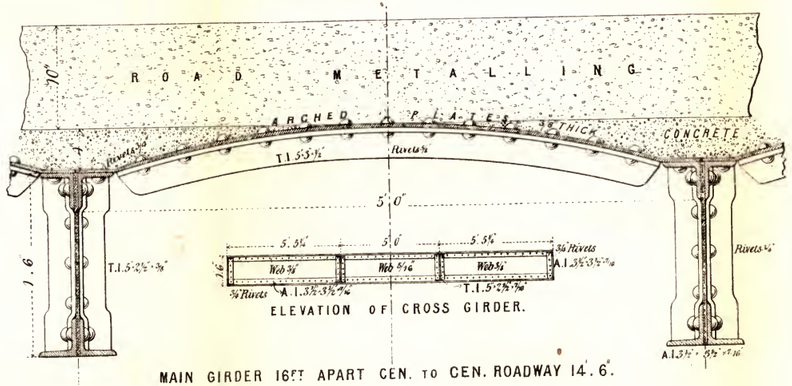


P



R

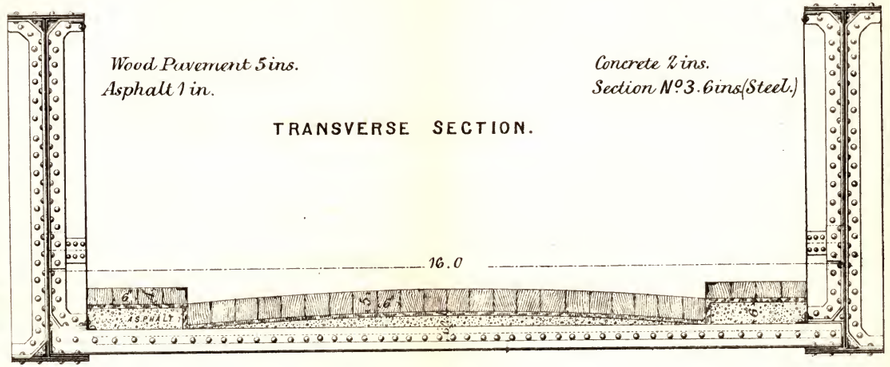
LONGITUDINAL SECTION



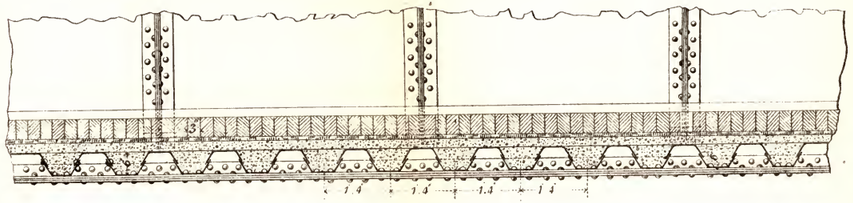
ELEVATION OF CROSS GIRDER.

MAIN GIRDER 16FT APART CEN. TO CEN. ROADWAY 14'.6".

Q



LONGITUDINAL SECTION.



E. & F. N. Spon, London & New York

aggregate area of 38 square inches. The strain, therefore, would only be about 8 cwt. per square inch, and instead of being 4 inches apart, the rivets might be very well 6 inches or 8 inches apart. Even assuming that the load was on one flute alone, there would be No. 32 rivets to carry the shearing strain of 14½ tons, equivalent to 1½ tons per square inch of rivet, while the top and bottom tables would be strained to 5 tons. Mr. Gill considered that there could be no advantage by fixing the floor on independent angle-irons; he however begged to differ on that point, having had considerable experience in this matter of construction. When the end of the floor rested on the main angle-irons of the girders the rivets belonging to the girder must be used to fix the floor, which gave much trouble, and this was entirely avoided by the use of independent angle-irons.

In reply to Mr. Light's question as to the prices on which he had framed his estimates, they were as follow :—

	£.	s.	d.
Cross girders, rail bearers, arched plates and bracing fixed, per ton	13	0	0
Rolled flooring (steel), fixed .. .. „ „	12	0	0
Rolled and corrugated flooring (steel) about 7 inches deep, fixed .. .. „ „	11	10	0
Large built iron flooring, fixed .. .. „ „	11	10	0
The same in steel .. .. „ „	13	10	0
Barlow rails, fixed .. .. „ „	10	0	0
Timber baulks, fixed .. .. per cubic foot	0	3	6
Planking, fixed .. .. „ „	0	3	6
Concrete .. .. per cubic yard	0	8	0
Brickwork in cement .. .. „ „	1	10	0
Metalling for roads .. .. „ „	0	3	6

April 4th, 1887.

HENRY ROBINSON, PRESIDENT, IN THE CHAIR.

THE SHONE HYDRO-PNEUMATIC SEWERAGE SYSTEM.

BY EDWIN AULT.

THE system of sewerage originated by Mr. Shone has for its object the surmounting of various difficulties inherent to the systems hitherto in vogue, and which arise, on the one hand, from the necessity (because of cost) of keeping the sewers within reasonable depths, and on the other hand, from the desirability of suiting the works to dealing with water-carried sewage. It will be seen, however, that the Shone system can be also applied, as it has been successfully applied, to simplify and economise the dealing with the transmission of sewage in the more concentrated forms of "pail contents" and of "sewage sludge." It is probable further that the limit to the variety of its applications has not yet been reached.

There are a few leading principles in connection with the subject, some of which will no doubt be considered vital, and all are of high importance to a successful and sanitary sewerage scheme.

(*a*) All rainfall upon streets, houses, yards, &c., should be conveyed away separate and distinct from sewage, to the utmost practicable extent.

(*b*) The sewage should be conveyed in pipes of such sizes, and at such gradients, as will give it a velocity from, say $2\frac{1}{2}$ feet per second in the larger volumes, to 3 or $3\frac{1}{2}$ in the smaller volumes.

(*c*) Regular and efficient flushing should be provided.

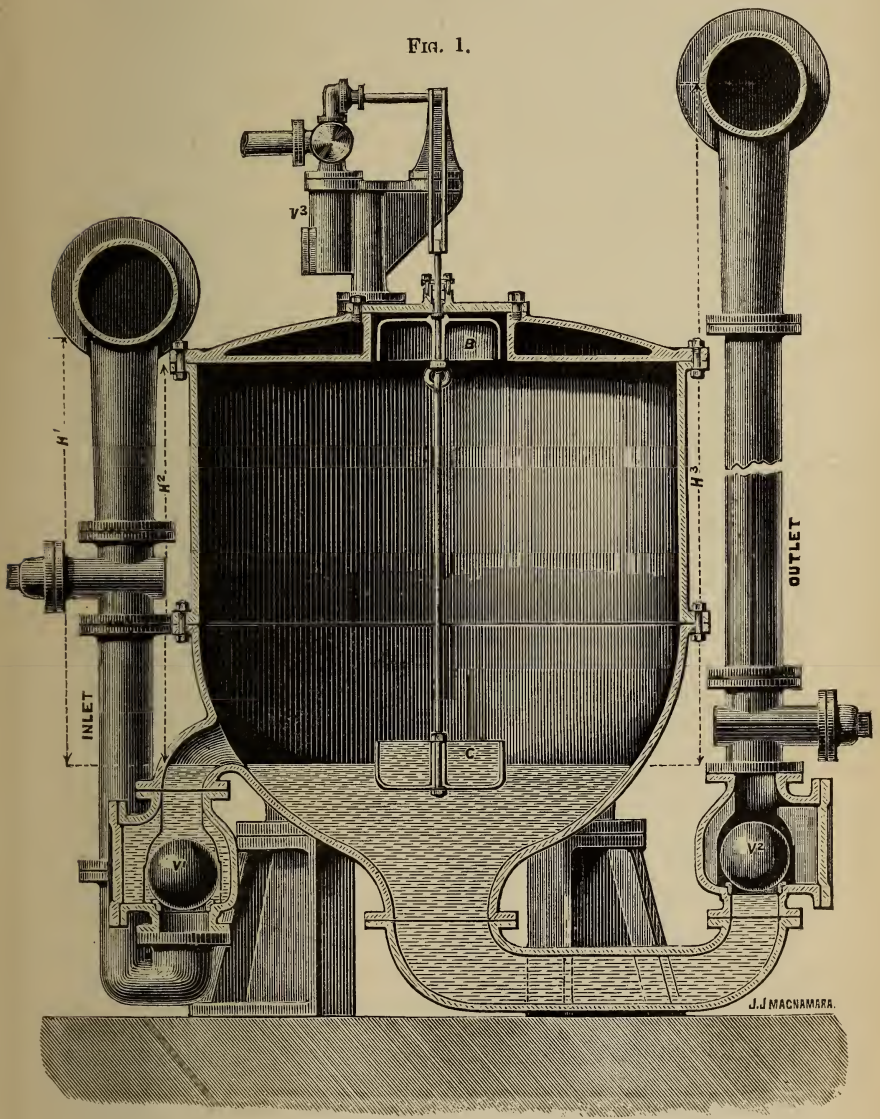
(*d*) No impounding or storage of sewage should be permitted between the source and destination.

(*e*) The action of the whole scheme should be automatic, so far as possible.

The difficulties in designing a satisfactory scheme, when rainfall is admitted into the same conduits as the sewage, are so great, that the wonder is that engineers have not set their faces

more energetically and emphatically than they appear to have done against any such proposal, long ago. For instance, the

FIG. 1.



drains must be of a size to accommodate the maximum rate of rainfall and sewage which may be expected, otherwise flooding

of basements and the low-lying places will take place. This means increased initial difficulty and cost of construction. It also means, in dry weather, when only the sewage proper is flowing in the conduits, a slow movement of the sewage, and also a large storage capacity for the accumulation of sewage gas; and, when rain occurs, this accumulated gas is displaced by the larger volume of liquid entering the drains, and is thereby driven up the connections to the dwelling-houses, and up the manholes (when ventilated) to the streets. Again, it means that road detritus and silt are washed into the sewers, and deposited on the inverts, seriously impairing the efficiency of the sewers as sanitary sewage carriers. Not only do such defects as these apply to the drains and sewers themselves, but the whole question of treatment and disposal at the outfall, and prevention of land, air, river, and sea pollution, is made considerably more difficult. Rule (*a*) is therefore considered a *sine quâ non*, for these and other reasons that might be adduced.

In dealing with the "separate system," a difficulty meets the engineer in adjusting the sizes and gradients of the sewers to the quantity of sewage.

1st. Because the sewage flows at various rates during various periods of the day. In the forenoon, for instance, speaking generally, a larger quantity of sewage is discharged per minute than during the night.

2nd. The natural gradients of the surface are not sufficient, except in comparatively rare instances, to correspond to the proper gradients of the sewers, so that in an ordinary gravitation scheme, either the engineer must fix flatter gradients than desirable, and make the sewers larger in diameter, or he must carry them down to great depths.

Theoretically, to convey a given quantity of sewage at a given velocity, only two sizes of pipe and two gradients are suitable, one size and gradient if the pipe is to run full bore, and the other if it is to run half full. So that theoretically a sewer should alter in size and inclination at every connection thereto. This, however, is impracticable.

Engineers have endeavoured to meet the difficulty by providing approximately such sized pipes, laid at such gradients as they could command (within such reasonable limits regarding depth as the surface would allow) as would convey the maximum flow of sewage away, though too often with slow velocities. The result of thus endeavouring to adapt the sewers to the circumstances, has been to lay down sewers of deposit, and consequently of decomposition, giving off large quantities of sewage gas.

What has been said so far refers to gravitating schemes of sewerage *per se*, but the remarks apply equally well, and perhaps in some cases more forcibly, to such schemes as include the pumping of the sewage, since pumping usually implies flat surface gradients, and therefore the engineer will flatten his sewer gradients to what he would consider a safe maximum that he may reduce his lift to a minimum.

It is claimed for the Shone system that it enables the sanitary engineer to fulfil with reasonable perfection the conditions laid down in the foregoing rules, and it will be the aim of the author to set forth such descriptions of the system and of works that have been carried out under the direction of Mr. Shone and his firm, and other engineers, as will establish this claim.

As a preliminary, the author desires to state that while stress has been laid upon the necessity of adopting the separate system of sewerage when designing a scheme as a whole, he wishes it to be clearly understood that Mr. Shone's system may be and has been applied with advantage to works carried out for the conveyance of surface waters and sewage combined, as will be shown hereafter. Indeed, there is no reason, if such be the desire, why the hydro-pneumatic principle should not be applied to the dealing with either surface and subsoil waters or sewage, whether separate or combined.

One of the main objects of the system now described is to comply with rule (*b*) by adopting such means as will render the engineer independent of the natural profile of the surface. This is accomplished by using iron receptacles called ejectors for the sewage, fixed in suitable positions, so as to allow of properly sized and graded sewers being laid thereto.

The ejectors may be of any size or shape found convenient; in fact, they have been made in many various forms and sizes. Preference, however, is given to those having the lower portion of hemispherical shape. The motive agent actuating the ejectors is compressed air. A reference to Figs. 1, 2, and 3 will enable the author to explain the action of the apparatus.

The sewage gravitates from the sewer through the inlet valve v_1 into the ejector, and gradually rises therein, until it reaches the under side of the bell B. The air at atmospheric pressure inside this bell is then enclosed, and the sewage continuing to rise outside and above the rim of the bell, compresses the enclosed air sufficiently to lift the bell and the spindle, &c. connected therewith, some $1\frac{1}{2}$ inch. This movement has carried over the slide valve of the automatic gearing (shown in detail in Figs. 2 and 3) so as to permit compressed air to act

FIG. 2.

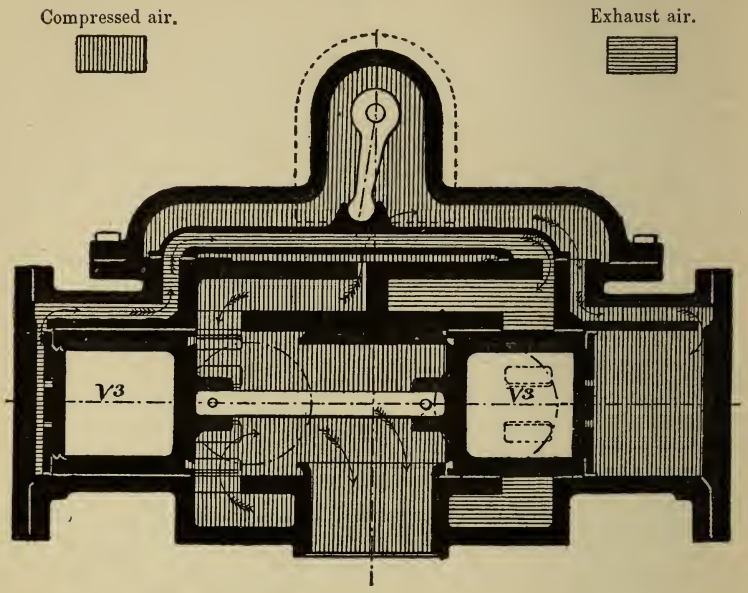
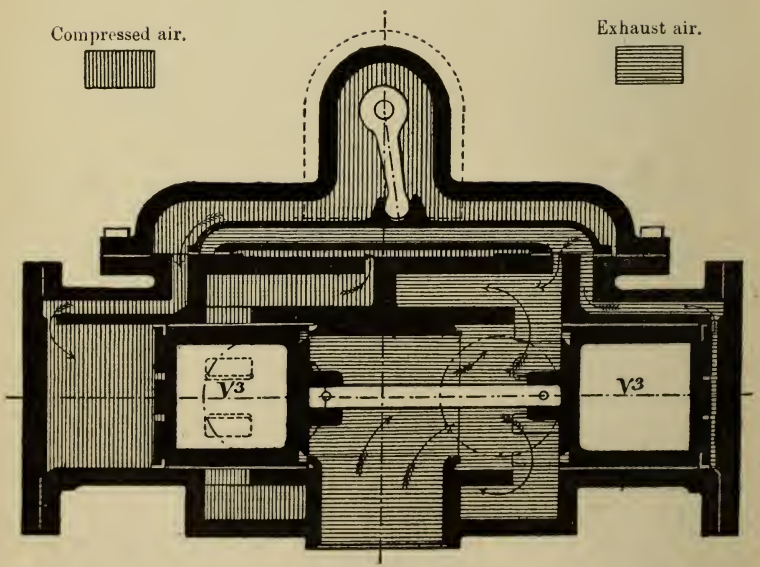

Compressed air.
Exhaust air.
V3
V3

FIG. 3.


Compressed air.
Exhaust air.
V3
V3

upon the main valve v_3. The latter is driven over to the position shown by Fig. 2. The compressed air then passes through the ports of the main valve on to the surface of the sewage in the ejector, and the sewage, being prevented from returning into the sewers by the inlet valve falling on to its seat, is forced through the delivery valve v^2 into and along the sewage main. As the sewage passes out of the ejector, its level therein reaches the cup C, and continues to lower, leaving the cup full until the weight of liquid therein is sufficient to pull down the bell, and the spindle, &c., connected therewith, thus reversing the action of the slide valve, and admitting compressed air to act on the opposite end of the main valve, driving it over to the position shown in Fig. 3. This first cuts off the supply of compressed air to the ejector, and then allows the air within the ejector to exhaust down to atmospheric pressure. The delivery valve falls on its seat, retaining the liquid in the sewage main; the sewage then flows into the ejector through the inlet once more, and so the action goes on as long as there is sewage to flow and compressed air to act.

It will be observed that (1) the compressed air is not admitted to the ejector until it is full, and (2) the air is not allowed to exhaust until the ejector is emptied down to the discharge level. In consequence of these actions the sewage is dealt with just as it flows from the sewers, whether it be at the maximum or minimum rate, and so far as the action of the ejectors is concerned, it matters not how much the difference between the two rates of flow may be.

With regard to the motive agent, compressed air, it has no doubt been strongly decried as a means of transmitting power; the author ventures to think unjustly so to a great extent, as he believes a large share of the blame should be placed to the discredit of the machines which have been used to compress the air. This is a subject, however, which could not be dealt with in the limits of the present paper.

Suffice it to say that the author has personally investigated a number of good and bad air compressors, which confirm him in the belief that good air compressors are rare and are of modern date. The magnificent installation now in process of construction at Birmingham, whereby 15,000 horse-power will be developed by compressed air, is a proof of the correctness of what has just been stated as to the efficiency of compressed air, and the further fact that the President of the Society, Professor Robinson, is associated with Mr. John Sturgeon as engineers for the work, affords additional confirmation.

It may be said that one important source of loss in using

compressed air is obviated in the apparatus under discussion, viz. the frictional and clearance losses of the executive machine, since there are no solid cylinders or pistons, with their connections, used for raising the sewage as in pumps, engines, rock drills, &c. In the ejector, the air itself is the piston, the body, the cylinder, and of course no piston or connecting rods are required, the friction therefore is infinitesimal. Again, an advantage which compressed air has over other power-transmitters is the small amount of friction opposing the passage of air through pipes. Indeed this friction is so small that, in designing a sewerage scheme on the pneumatic system, it may be left out of count altogether, except where the air mains are of great lengths, and (on the score of economy in first cost) are of small diameter; and even in these cases the friction will be but a small objection as compared with other agents.

Fig. 4 is a diagram for ascertaining volumes of air, &c., for estimating approximately the size of air-compressing machinery to be used in connection with the Shone hydro-pneumatic system, when the maximum quantity of sewage in gallons per minute and the height of lift are known.

The lift must include friction in the pipes, and from 4 *to* 6 *feet for drop into the ejector.*

Explanation.—1. The part A B. The first divisions show respectively the height of lift in feet and the pressure in pounds per square inch corresponding to the same; and the remaining division shows the volume of free air to be compressed in cubic feet per gallon per minute of sewage.

The size of one double-acting air-compressing cylinder is found when L = volume (in cubic feet) measured from diagram, D = diameter of cylinder in inches, P = piston speed in feet per minute.

$$D = \sqrt{\frac{L \times 183}{P}}$$

2. The part B C. The ordinates show the height of lift in feet, the abscissæ show the horse-power required per gallon of sewage lifted to this height per minute.

The first curve shows the net horse-power performed in lifting one gallon of sewage per minute to the height = H, calculated from the formula—net horse-power $= \frac{10\ H}{33{,}000}$.

The second curve shows the indicated horse-power in the air-compressing cylinder required for compressing the free air used

in a Shone ejector per gallon of sewage per minute lifted to the height H, calculated from the formula

$$\text{H.P.} = 0{\cdot}176282\,\frac{p_2}{p_1}\left\{7{\cdot}35\log_e\frac{p_2}{p_1} + 25{\cdot}2761\left[\left(\frac{p_2}{p_1}\right)^{0{\cdot}2907} - 1\right]\right\}$$

where p_2 = absolute pressure of air corresponding to the lift H.

p_1 = absolute average pressure of atmosphere.

The third curve shows the actual indicated horse-power of the driving engine required for the Shone system per gallon of sewage per minute lifted to the height H. It is found by adding 15 per cent. for friction to the above values. The friction of course varies somewhat with the size and design of the engine.

The fourth curve shows the indicated horse-power required to drive a centrifugal pump per gallon of water per minute lifted to the height H, calculated from the formula given in Mr. D. K. Clark's Manual,

$$\text{I.H.P.} = 0{\cdot}0001807\ \text{H}^{1{\cdot}5}$$

3. The part C D. The ordinates show the height of lift in feet, the abscissæ show the useful effect of the Shone system = U.

$$\text{U} = \frac{\text{Actual horse-power in water lifted} \times 100}{\text{Actual indicated horse-power of driving engine}}$$

In using the diagram, the lengths of the ordinates perpendicular to any given height, applied to the scales at the bottom of the diagram, will give the values of the various quantities; thus to raise one gallon of sewage 25 feet high, the maximum lift at the Houses of Parliament (see the asterisks on diagram) will require 0·3 cubic feet of free air compressed to 10·8 lb. per square inch. The net horse-power in work of sewage raised would be 0·0075, the horse-power lost in compression 0·004 and in friction 0·0015, or a total indicated horse-power in the driving engine of 0·013, giving out a useful effect equal to 58 per cent. For comparison, the horse-power required to be developed in driving a centrifugal pump is equal to 0·0225, or 42·2 per cent. in excess of that required by the pneumatic method.

It will be understood that the employment of ejectors enables the engineer to divide a town into suitable districts, according

to local conditions of gradients, population, outfall, &c., each provided with an ejector station containing one or more ejectors. In flat towns, the districts would be fairly regular in size and distribution; in undulating places they would vary in size, &c. In some places part of the sewerage of the town may be dealt with by gravitation, and the rest by the aid of the ejectors. Each separate place would govern a scheme in its details, by the special circumstances attaching thereto, but the principle is the same throughout.

The ejector station is practically the "outfall" of the district to which it is attached, and the district is as effectually separated from the other parts of the town, so far as its sewage is concerned, as if it were delivered to an entirely separate destination. This may prove an important feature in localising and dealing with the causes of infectious diseases.

Among the advantages of dividing a town into separate sewerage districts are (1) that it enables the engineer to cause the sewage to be carried in small pipes of short lengths and with good gradients, as will be illustrated hereafter. It follows from this that the space for the storage of sewage gas is thereby within narrow limits. (2) Since obedience to the rules laid down implies quick flow of the sewage, and the sewers along which it flows are comparatively short in each district, the sewage has no time to decompose before it is sealed up in the iron sewage main; once it is there, it has no contact with the atmosphere until it reaches the outfall. (3) The volume of air in the gravitation pipes being small, the action of the sewage flowing therein, especially when regular flushing is resorted to, would be to frequently replenish the air within them, and so keep the whole system fresh and healthy. (4) By reason also of the smallness in diameter and shortness in length of the pipes, the volume of the water required for regular flushing, and the volume of air required to ventilate them, is reduced to a minimum.

In connection with the dividing of a town into districts for the purpose of applying the Shone system, it should be stated that the consumption of compressed air would not be appreciably increased by reason of multiplying the number of divisions. From one compressing station a number of ejector stations can be supplied as economically (in fuel cost) as if the whole of the sewage were brought to one spot, and raised thence to an equal height; and when it is remembered that in many cases, by collecting the sewage in districts, instead of gravitating the whole down to the lowest level, the gross lift is thereby reduced, it will be seen that the more economical way

would be to so distribute the ejector stations. Speaking broadly, it is more economical to use compressed air at a low pressure than a high one, consequently it would be better in some cases to break up a lift into two or more sections, and use air at a low tension, than to have one lift, using air at a high tension. So that a division of the town would help the engineer in this way.

By the adoption of the Shone system, all storage reservoirs and "tank sewers" are entirely done away with. These abominations were necessary under the old régime, where pumping was adopted in order to allow the working of the pumps to be fairly uniform, and where the sewage was discharged into a tidal river or the sea, at or near low-water mark, in order to impound the sewage when the tide was up. By reference to the drawings it will be seen that the raw unscreened sewage passes out of the gravitating sewers directly into the ejectors, and passes out of them directly into the sewage main to the outfall.

Before passing from the part of the paper which may be called a general description, the author must vindicate the use of the word *hydro*-pneumatic in the title, as well as show how rule (*e*) is complied with by referring to Mr. Shone's automatic hydraulic flushing ejector or tank.

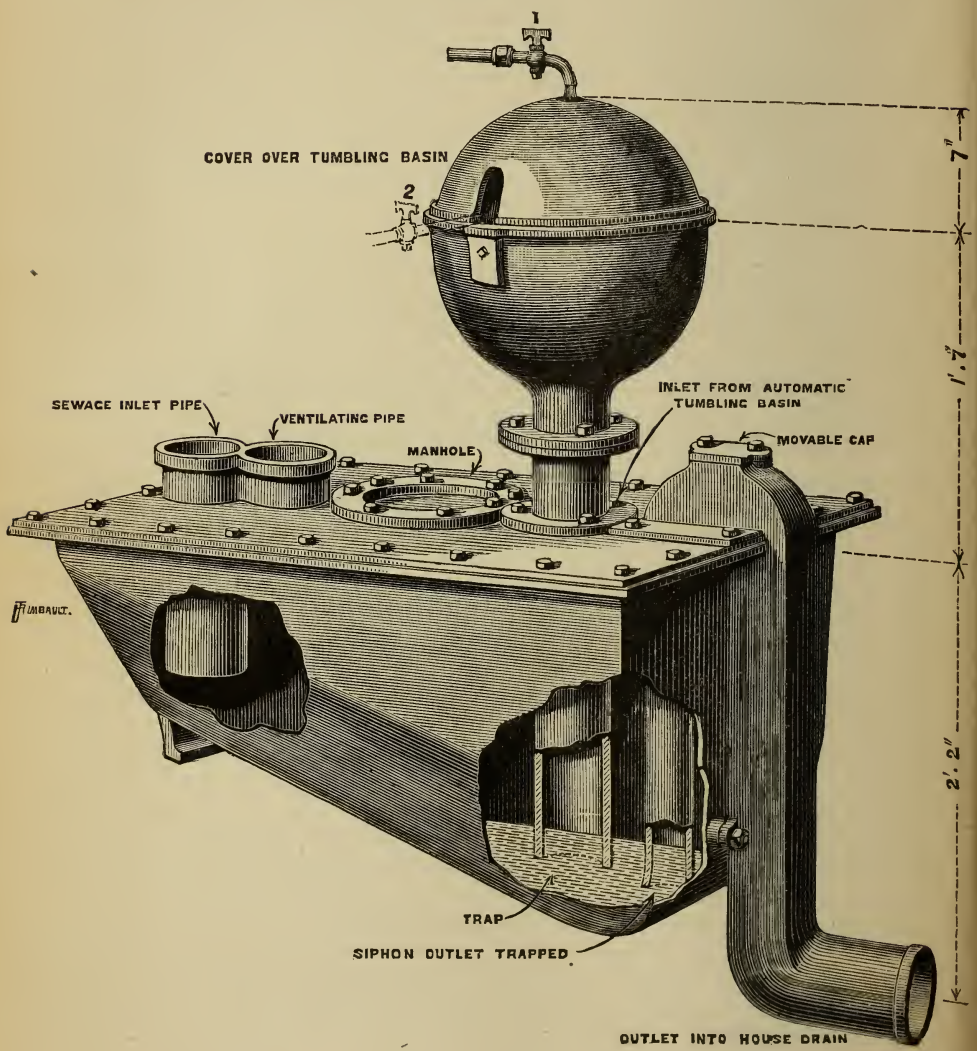
The importance of flushing for the purpose of keeping sewers in a sanitary condition is generally acknowledged, and needs no advocacy here; but the methods of flushing in most cases are faulty, for various reasons, viz. because the flushing is attempted too frequently by pouring a stream of water down a manhole through a fire hose from the nearest hydrant, and, since water companies must not be robbed, before the water reaches the manhole it must pass through a meter, and what with the friction through hydrant, meter and hose, &c., by the time the water reaches the sewer it is insufficient in force to properly do the work required. And, again, when tanks are provided in which a volume of water may be collected, and suddenly let into the sewers by the lifting of a sluice, they are either forgotten altogether or dependent upon the fidelity and regularity of workmen who unfortunately have not got a superfluous stock of those estimable qualities.

The Shone house sewage and hydraulic flushing ejector will be understood by a reference to Fig. 5.

It consists of a watertight tank provided with a siphon and a tumbling basin, and its action is as follows:—A small stream of water (or say the lavatory waste) is constantly fed into the tumbling basin of the house sewage ejector, and these fluids

cause it, when full, to topple its charge into the tank. Water, slops, or sewage is also supplied to the tank direct; when the

FIG. 5.



latter is full, the liquid begins to flow over the siphon, and the next discharge of the full basin suddenly fills the siphon bend

and starts the siphon in action, which continues until the contents of the tank are drawn off. The operation of the apparatus can be so adjusted as to cause it to discharge at regular intervals, according to requirements: it is self-cleansing, has a free way for the passage of solid particles, is thoroughly trapped, and is certain in its action.

By the use of automatic flush tanks, properly distributed throughout the sewerage works, constant and regular flushing of the sewers would be obtained with a minimum consumption of water, and so fulfil the conditions laid down in rules (*c*) and (*e*)

Having so far given some of the leading and general points of consideration, it remains to refer to some of the works executed upon the system; and for the purpose of presenting a variety of features, the author has chosen three typical cases for description, of which two are examples of the "combined" and the other an example of the "separate" system. It is proposed afterwards to refer to works carried out for the transmission of "pail contents" and "sewage sludge."

The first case taken is Eastbourne, which was the first public instance in which the Shone system was applied to sewerage works.

It will not be necessary to give many particulars regarding the town of Eastbourne, as it will no doubt be familiar to most if not all the Members. Suffice it on this head to say, that the population at the 1881 census was 21,595, which showed that it had more than doubled the record of the 1871 census. The population in the season, however, springs up to as many as 70,000 or 80,000. The western and better class portion of the town is somewhat elevated and undulating, but with some awkward basins here and there; the eastern and oldest portion is almost a dead level. The original sewerage works were designed and carried out in 1865, under Mr. G. A. Wallis, C.E., as engineer, and were upon the gravitation plan throughout. The main sewer was carried through the eastern portion of the town, under the flat surface, and out to low-water mark at Langney Point, over two miles from the centre of the town, where a shore current carries the sewage out to sea. During high water, of course, the main sewer was tide-locked, and a good deal of labour was regularly expended in clearing the silt deposited during the lock on the invert of the main sewer. About 1880, Mr. Wallis heard of the hydro-pneumatic system, and after seeing Mr. Shone's experimental works in successful operation on Colonel Jones' farm at Wrexham, he thought it would be a valuable supplement to the Eastbourne sewerage works, the result being that Mr. Shone received instructions to

prepare a scheme which in due course was approved of and carried out in 1880–1.

Plate A will illustrate the scheme now referred to. On the main sewer, where it turns from the Hastings Road along the beach, and about $1\frac{1}{4}$ mile from the outfall, was fixed a penstock to shut off the tidal water, and under the road near by was built an ejector station B, containing three pneumatic ejectors, cylindrical in shape, each of 600 gallons discharging capacity. The "inlet" pipe supplying these ejectors is led from the main sewer on the town side of the penstock, and the "discharge" pipe from the ejectors is carried to the main sewer on the outfall side of the penstock, thus ensuring that whatever may be the height of the tide, the sewage of the town shall be constantly discharged as fast as it flows down. This desirable condition has been maintained ever since the works were started.

The compressing station A is situate about 300 yards from the main ejector station B, the compressed air to the latter being conducted through a 6-inch main. The air is supplied by a pair of Sturgeon's trunk compressors, capable of being worked together or alternately, each engine having two single-acting air cylinders 14 inches diameter, the pistons being worked direct from the piston rod of the steam cylinders; the latter are $10\frac{1}{2}$ inches in diameter, the stroke of all the pistons being 2 feet. Behind the steam cylinders are fixed two condensers, also worked direct from the steam piston rods. The steam is supplied from two 10 horse-power Kesterton boilers (worked alternately), at 60 lb. pressure, the cut-off in the steam cylinders varying from about $\frac{1}{3}$ to $\frac{1}{8}$ of the stroke. The air pressure is maintained at from 11 to 14 lb. Besides the air for the main ejector station already described, the compressors also supply air to two other ejector stations in the town, established since these first works were carried out.

In one of the best parts of Eastbourne is situate the "Wish Valley," a basin which lay too low for drainage by gravitation into the main sewers, and was too pretty a place to be desecrated with a pumping establishment. The property belonging to the Duke of Devonshire, his Grace, under the advice of his engineer Mr. Wallis, put down an ejector station D, for the purpose of dealing with the sewage of the Wish Valley area. In this station, which was opened in April 1882, are fixed two ejectors of about 300 gallons capacity each, the bodies being of wrought iron, embedded in concrete. The air is conducted through a 4-inch cast-iron main from the compressing station already referred to, which is about 10,000 feet away. The sewage is discharged into the general system of the town, and finds its

way down to the main ejector station. It is interesting to observe that the drainage of the whole area of the Wish Valley basin is, and has been, wholly dependent upon the ejectors, since, from its situation, a storm overflow cannot be provided.

In 1885, a third ejector station C was put down in what is called the Bourne Valley, situate in the flat eastern part of the town, for the purpose of obtaining improved gradients in the sewers of the district. In this station, situate about 5000 feet from the compressors, are placed two 350-gallon ejectors, spherical in shape, and discharging the sewage into the main sewer which runs close by. The ejectors are supplied with air through a branch off the main leading to the Wish Valley station.

The cost (as given in an official report by the Chairman of the Highways and Drainage Committee) of "the three stations, including ejectors, inspecting chambers, manholes, air and sewage mains, compressors and boilers in duplicate, engine-house, boiler and receiver house, two cottages for the engineer and stoker, including land, engineering, law, and other expenses, amount in the aggregate to about 8500*l.*," and the "annual cost for running the plant, including engineer, stoker, fuel, water, oil, tallow, &c., is about 600*l.*"

The works at Eastbourne are evidence that (1) The Shone system can be successfully applied to combating the difficulties of a tidal outfall. (2) It is a valuable adjunct to existing gravitating schemes in dealing with difficult places, such as low-lying basins and flat districts. (3) It can be easily established in sections from time to time, as occasion may dictate. (4) It is economical as to choice of sites for the works, as the surface buildings need not be confined to any particular spot, and the other works may be under the public streets.

The second case which the author has the honour to draw attention to is the Main Drainage of the Houses of Parliament, the history of which is not only interesting, but instructive.

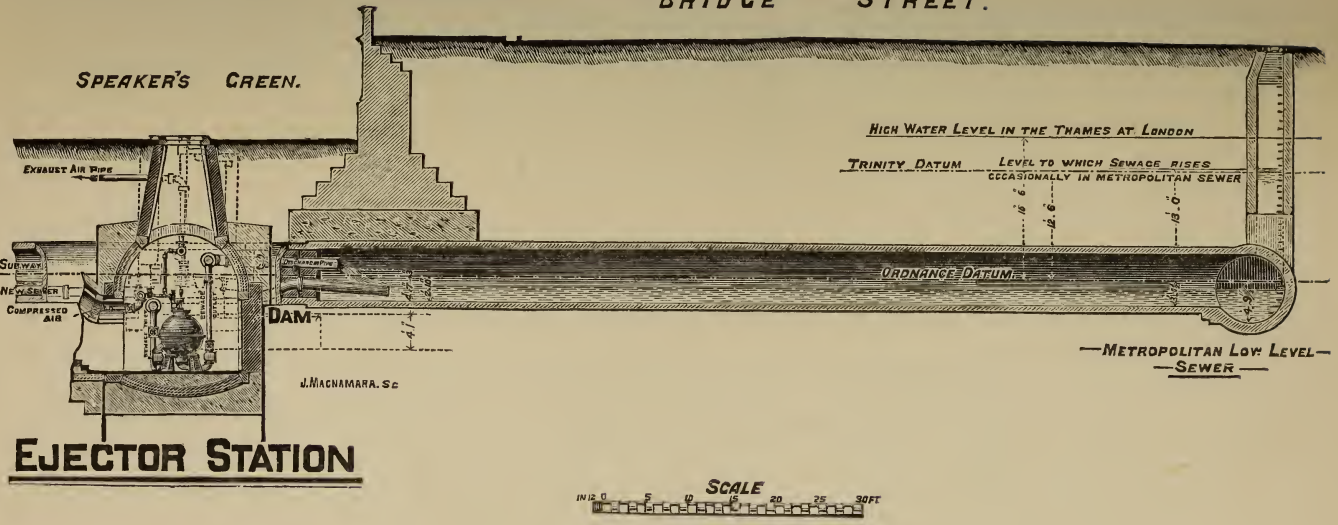
The original main sewer constructed by Sir Charles Barry in 1839 (of the form shown by section *a a* on Plate B), ran under the whole length of the premises, to the Victoria Tower end, and discharged into a similar sewer in Abingdon Street. In consequence of its flat gradient and invert, it was always a sewer of deposit, and constantly gave off noxious effluvia which found its way into the Palace. In 1848, under advice from Mr. John Phillips, C.E., the fall of the main sewer was reversed, and the form of its invert, as well as the gradient, improved, as shown by section *b b*. The discharge was now into a sewer in Bridge Street, about 5 feet lower than the one in Abingdon Street. This alteration enabled two main branch drains to be laid, draining both sides of the Palace, and joining the main

sewer near its lower end. Not only was the velocity of flow in the Palace sewer increased, by reason of the better gradient, but the outlet was improved by its being connected with the Bridge Street sewer, which discharged direct into the Thames. This arrangement was so far satisfactory that complaints of smells apparently subsided. But about 1873, the Metropolitan low-level sewer, 7 feet 9 inches in diameter, was put down through Westminster, and the Palace sewer was connected with it, its invert at the junction being about 21 inches above that of the Metropolitan sewer. Ever since this work was done, there has been daily, in dry weather, from 3 feet 6 inches to 4 feet in depth of sewage flowing on the bottom of the Metropolitan sewer, and this created a constant head of sewage against the Palace sewer outlet, converting it for a length of about 200 feet into a creek, containing from 1 foot 9 inches to 2 feet 3 inches in depth of nearly stagnant sewage. But, besides this, in wet weather the Palace sewer was not only filled with sewage water, but sometimes this water has risen to 10 feet above the crown of the Metropolitan sewer. During wet weather, therefore, the Palace sewer and its branch drains have been filled with sewage and rain-water, which could not be discharged until the flood-water contained in the Metropolitan sewer had subsided. Hence, for twelve or thirteen years past, the Palace sewer, as well as its main branch drains, have been periodically converted into sewage gas reservoirs; and from these the sewage water, as it accumulated and filled them, drove the gases up the various contributing drains into the Palace. This discharge of sewage gas into the Palace went on more particularly at night time, during the sessions of Parliament, when the gas was burning throughout the Palace, and when the waste hot water and steam, from the warming and ventilating appliances of the Palace, were discharged into the drains and sewers, and fermented the sewage lying therein. The unpleasant effects, caused partly by the Metropolitan low-level sewer, and partly by the sewer and drains under the Palace, as already described, became at last so intolerable that Parliament referred the subject to a Committee of the House of Commons, the result being that after the deliberations of various Committees, the one appointed early last year, under the presidency of Sir Henry Roscoe, F.R.S., recommended to Parliament that the plan as proposed by Mr. John Phillips and supported by Major Hector Tulloch, R.E., on the Shone Hydro-Pneumatic System, should be adopted, and this recommendation has been substantially carried out.

Fig. 6 shows the details, and will illustrate the following description :—

In place of the then existing main sewer, which in consequence

FIG. 6.


BRIDGE STREET.
SPEAKER'S GREEN.
EXHAUST AIR PIPE
HIGH WATER LEVEL IN THE THAMES AT LONDON
TRINITY DATUM
LEVEL TO WHICH SEWAGE RISES OCCASIONALLY IN METROPOLITAN SEWER
16'6"
12'6"
13'0"
SUBWAY
NEW SEWER
COMPRESSED AIR
DISCHARGE PIPE
DAM
ORDNANCE DATUM
METROPOLITAN LOW LEVEL SEWER
J. MACNAMARA. Sc
EJECTOR STATION
SCALE
IN FT. 0 5 10 15 20 25 30FT

of the reversal of the gradient had been enlarged in some places to 10 feet and more in height, a 12-inch cast-iron pipe was laid on the invert of the sewer (sections *c c* and *d d*, Plate B) and the latter converted into an inspecting subway. The branch drains, instead of discharging into the big sewer as heretofore, are grouped so far as practicable, and connected to iron branches on the new 12-inch pipe (see Fig. E, Plate B). The Western main branch drain is replaced by a 9-inch cast-iron pipe, at an improved gradient, which is connected to the 12-inch sewer near its lower end, as shown on the plan of ventilation, Plate B. A substantial dam is built in the old sewer under the Speaker's Green, effectually closing the free communication between the Palace and Metropolitan sewers. The ejector station, built under the Speaker's Green, contains 3 ejectors; one of 500 gallons, and two, each of 350 gallons discharging capacity. The sewage from the new iron sewers passes into a manhole adjoining the station, and from thence goes through the inlet pipe to the ejector, and is discharged through a 12-inch outlet pipe connected with the ejectors: the further end of the outlet pipe is built in the dam, delivering the sewage on the Metropolitan side.

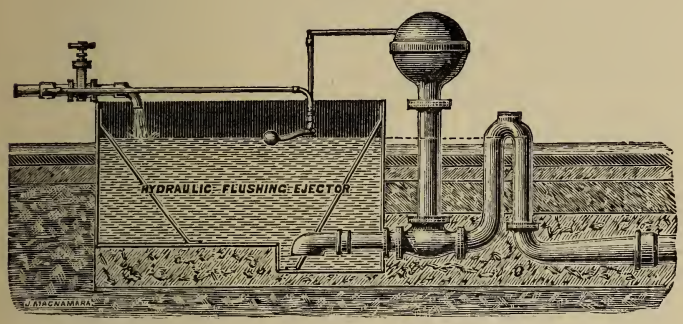
There is also built in the dam, and communicating with the manhole, a 12-inch iron siphoned pipe, having both a sluice and reflux valve attached, so that at any time during a spell of dry weather, the Palace sewage may be allowed to pass direct into the Metropolitan sewer without going through the ejector.

About 600 feet away from the Speaker's Green, and in the basement of the Palace, the compressing station is established, containing four compressors, attached to and worked by Atkinson's differential gas engines of 4 horse-power each. The compressed air is led along the basement, and a new subway leading to the ejector station, by 6-inch mains in duplicate. Constant currents of air are drawn through the subways, ejector station, manhole, and iron sewers, to the furnaces in the Victoria and Clock Towers.

Regular flushing is provided for, by fixing a hydraulic ejector at the head of the 12-inch and 9-inch sewers. The construction of these flush tanks is shown on Fig. 7, by which it will be seen that they are of different form from the one described in an earlier part of this paper. The tank portion is open at the top, and the tumbling basin is connected to the siphon pipe instead of the tank body, and on the tank side of the tumbling basin connection is a reflux valve. When the water in the tank rises to a sufficient height to act upon the ball tap, water begins to flow through a service pipe leading to the basin, which, when full, discharges its contents suddenly into the

siphon, and starts it in action, the reflux valve preventing the water from the basin passing into the tank, but allowing the tank water to flow freely out until emptied.

Fig. 7.



Ordinarily, one compressor only is working at a time, and it is capable of supplying sufficient compressed air to eject the whole of the sewage of the Palace, together with a moderate rainfall. When the flow of sewage and rainfall is such that it begins to rise in the manhole, an electrical bell and indicator, operated by a float therein, draws the attention of the man in charge, who then sets another compressor to work, and a third or fourth, if necessary. It is not anticipated, however, that the four compressors will be required, at any time, to work together, notwithstanding that the whole of the rain falling on the premises is allowed to pass into the sewers.

The works were carried out under Mr. Shone's direction as Engineer, and have cost a little over 11,000*l.*

One of the engines, compressing air to 10 lb., consumes about 2000 feet of gas in 24 hours, when working up to its full power; this makes the cost per horse-power per hour (reckoning the gas at 3*s.* 9*d.* per thousand) less than one penny.

The new works at the Houses of Parliament show the value of the Shone system, in isolating a house or district from general sewerage works and rendering the house or district sanitarily perfect, whatever may be the condition of the general works.

The third typical case of applying the Shone system is Henley-on-Thames, where the whole town has been sewered, under the direction of Mr. Shone as engineer. Plate C shows a plan and section of the sewerage as carried out.

The separate system was adopted, the result being that the gravitating sewers are throughout only 7 inches in diameter, the gradients in no case being less than 1 in 200, the junctions

being all 5 inches diameter. There are four town ejector stations (marked Nos. I. to IV.)—dealing with the town sewage in as many sections—each station having two 150-gallon ejectors. The outfall works are about a mile and a half from the town, and about 160 feet in height above the four ejector stations; and in order to reduce the tension of compressed air, an intermediate ejector station (marked No. V.), containing three 150-gallon ejectors, is placed so as to divide the lift into two sections. An iron sewage main varying in size from 5 to 8 inches in diameter, common to the four town ejector stations, conveys the ejected sewage to the intermediate station, and from the latter, it is ejected through an 8-inch iron main to the outfall tanks. Two settling tanks are provided at the outfall, into which the sewage is delivered alternately, and from which the effluent will be conveyed for purification and irrigation by carriers on to the adjacent ground now being prepared. The elevated situation of the outfall, and also of the intermediate station, will enable the Corporation to supply sewage to a large area of arable land, at any time that arrangements may be made therefor, and, of course, whatever sewage is delivered on to land from the intermediate station, will so far reduce the working lift for that portion.

The compressing station is established on the site of the outfall works, and contains two air compressors, for alternate working, built from a design of Messrs. Shone and Ault. Each engine has two single-acting air cylinders, 14 inches diameter, and 21 inches stroke, fixed vertically; one high-pressure steam cylinder, 11 inches diameter, and a low-pressure cylinder 19 inches diameter, both of 18 inches stroke, fixed horizontally. All the cylinders are connected to the same crank shaft. The exhaust steam is condensed by a pump worked with a driving chain from the crank shaft. Steam is supplied from two Lancashire boilers, at 60 lb. pressure, the cut-off in high and low-pressure cylinders varying from ·3 to ·6 of the stroke. The air is compressed to 35 lb., and is led through a 4-inch main as far as the intermediate station, and afterwards through a 3-inch pipe to the four town stations.

The total cost of the works, including legal and preliminary professional charges, purchase, and preparation of land, and all the various charges on the town sewerage account will be about 18,000*l.*

From preliminary trials conducted it has been found that the indicated horse-power averaged about 21 horse-power, with 49 revolutions per minute. The supply of compressed air was sufficient to raise 160 gallons per minute the whole lift of 160 feet, including friction. The consumption of coal was 2·8

pounds per horse-power per hour. The grate area under the boilers was too large for the small quantity of fuel consumed, the stoking indifferent and the friction far too high.

Briefly, the works at Henley are, in the author's opinion, a practical demonstration of a successful and economical adaptation of the Shone system to a town having good surface gradients down to the river, but with a flat gradient along the synclinal axis of the valley, and with ground unsuitable to outfall works in a gravitating scheme, or low pumping, by reason of its being water-logged. These works also illustrate the usage of small pipes for the gravitating sewers.

It only remains now for the author to refer shortly to the application of the ejectors for the transmission of "pail contents" and "sewage sludge."

The first of these special applications has been carried out at Warrington, where the main depôt for the treatment of pail contents is situate about a mile and a half from the town. Prior to adopting the ejectors, the pails were carted direct to the main depôt, involving the use of 15 vans, with their attendants, for the purpose. Mr. Longdin, the borough surveyor, having had some acquaintance with the Shone system, from its being applied to the sewering of Latchford (a part of the borough of Warrington), and having made some preliminary experiments as to the capability of the ejector for dealing with pail contents, worked out a scheme for effecting a considerable saving in horseflesh, &c., by establishing two auxiliary depôts in the town, for emptying the pails, and from these depôts, to discharge the contents to the main depôt at Longford, through an iron main. At each of the auxiliary depôts is fixed a wrought-iron tank, into which the pail contents are emptied, and which is capable of holding 2 days' collection. From the bottom of the tank, a pipe conveys the crude sewage to an ejector, and from the ejector it is discharged into the main leading to Longford depôt. The compressed air is supplied by compressors, already planted at the gasworks (belonging to the Corporation) for working the Latchford ejectors, as they were found to be of ample capacity to operate the two schemes.

One of the auxiliary depôts has been in successful operation now for six or seven months, and the other for about two months. Mr. Longdin, who has managed the whole matter, expresses himself as thoroughly satisfied with the result, and is sanguine that the change will save the Corporation over 1000*l.* a year in the cost of collecting and conveying the pail contents to the main depôt. The whole works at Warrington are well worth a visit, both because of the novel mode of transmitting the pail stuff to the depôt and because of the excellent method adopted

for converting the stuff into pouderette manure, which is sold there regularly for from 6*l.* 10*s.* to 7*l.* per ton.

Last year also witnessed the application of the Shone system at Southampton for the transmission of sewage sludge from the settling tanks to some of Fryer's admirable destructors, which are erected there.

The ejector is sunk in a cast-iron chamber, piercing the floor of the settling tanks, and the sludge, when ready, gravitates into the ejector, and is discharged through a 4-inch iron main 1500 yards long on to the feeding floor of the destructors, in which it is burnt along with refuse from the town. Thus we find that the solid wastes of Southampton are cremated by Fryer's destructors, and in the process steam is generated to expel the fluid wastes away from the town.

This is another instance of the favour which the system gains with intimacy; Mr. Bennett, the borough surveyor of Southampton, having had experience with the ejectors by their being applied to dealing with the sewage of a low-lying part of the town, and being led thereby to apply them to dealing with the sludge. The special works were designed by and carried out under Mr. Bennett's direction.

In conclusion, the author ventures to hope that he has set before the members of the Society, such particulars as will enable them to express their views upon the alleged advantages of a system to which he has devoted much time and attention during the last few years; and he hopes that any shortcomings in regard to the system, which may appear at first sight, may be set down rather to his want of ability in setting forth its claims, than the incapability of the system, since he feels that the more engineers become familiar with its capabilities, the more will they realise the fertility of its resources and application to an almost endless variety of conditions affecting the all-important question of town drainage.

DISCUSSION.

The PRESIDENT, in opening the discussion, said that the first part of the paper referred to matters which governed all sewerage systems. The basis of Mr. Shone's system was the very ingenious appliance which was known as the ejector. With reference to employing good gradients, avoiding large outfall sewers, which, when tide-locked, became sewers of deposit, and the separate system, all these must necessarily apply to every system of sewering a town, and Mr. Ault's practical remarks upon them would be no doubt appreciated by

all engineers. He (the President) did not agree with the author as to the alleged objection to the use of compressed air. If there was such an objection, it arose from the fact that there was a great amount of ignorance prevailing with regard to the employment of compressed air. The results of applying compressed air at a high pressure had very often been applied to compressed air at low pressures, and a wrong conclusion had thereby been made. The faults in many sewerage systems arose largely from the action of the Local Boards themselves, who considered that anybody could lay out a system of sewers; and people were employed who had no experience in this kind of work. Sometimes a scheme of sewers was devised for an existing population without due regard to the prospective increase; a bad beginning for a sewerage system, and one that entailed serious complications as the town developed. In his judgment, the cases in which the Shone ejector could be applied with great advantage, were those in which the installation of a pumping station would be most objectionable, owing to local opposition. In such a case the power of establishing a compressing station at a convenient place, free from any risk of interference with building lands, and transmitting the power required to raise the sewage from one level to another, by means of compressed air, gave a great advantage and from an engineering point of view was easily effected. It was a great fallacy to assert that any serious loss of power took place in the transmission. Power could be transmitted by compressed air without any appreciable loss. The ejector, which had been described in the paper, was, in his opinion, one of the simplest forms of appliance by which compressed air could be used for raising fluids. In cases which often occurred in practice where the outfall would have to be with a flat gradient, and perhaps delivering into the sea at a point below high-water mark, he considered that the Shone ejector could be applied with advantage, as it had been applied at Eastbourne. Where a sewer had to be carried to a pumping station and its course in a direct line would be through very bad ground, at a great depth, involving heavy expense and risks of slips and settlements; the necessity for costly works might be avoided by keeping the sewer at a higher level and having an intermediate lift by an ejector. The risk of the subsidence of the adjoining houses would be avoided and the reduction of pumping would be ensured. He had lately advised the adoption of such a plan at Heston and Isleworth, by means of which a great amount of the anxiety which would be occasioned if the sewer was carried through the district by direct gradients through very bad ground would be avoided. It had been suggested that some

very useful figures might be added to the paper. If Mr. Ault could give fuller information with reference to the volume of sewage raised at the various places mentioned in the paper, and the cost of raising it, it would be an advantage to have the information before the discussion proceeded.

Mr. AULT said that it was really very difficult to get any figures in either of the cases because of the very variable flow. At Eastbourne the plant had dealt with about 2500 gallons a minute at the main station. This had been lifted to a height of about 16 or 17 feet. Of course that was an extraordinary flow.

Mr. R. W. P. BIRCH said that it would be very important if Mr. Ault could give them the fine weather flow.

Mr. AULT said that the fine weather flow at Eastbourne was something like 1800 gallons every six or seven minutes at the three ejectors. In the case of the Houses of Parliament the flow was about 500 gallons every quarter of an hour. One ejector went off every quarter of an hour. The minimum lift would be about 12½ feet. Since the works had been established at the Houses of Parliament they had not had any very heavy storm. He believed that the maximum rate which had been observed there had been 500 gallons about every 2½ minutes raised about 18 or 20 feet. He could not give any figures with regard to the quantity at Henley, as the connections had not been made.

Mr. PERRY F. NURSEY being unable to attend the meeting, the following written communication from him was read by the Secretary:—

"I regret that my illness, from which I am now happily recovering, will prevent my being present at our meeting on Monday evening, as, being familiar with the working of Mr. Shone's excellent hydro-pneumatic system, I should like to have borne verbal testimony to its efficiency, so far as my observation has extended.

"I first examined the system at Eastbourne some years since when it was being put down there, but as it had not then been started I could only form a general opinion as to its probable merits, but that opinion was in its favour. During last year, however, I inspected the system of sewage disposal at Southampton, where the sewage is treated with a deodorant which acts also as a precipitant. There are two settling tanks worked alternately, the effluent water being discharged into Southampton Water by the aid of Shone's ejectors, and the sludge being conveyed by means of another ejector to the destructor station about a mile off. I was particularly struck with the quiet but effective manner in which all the functions of these ejectors were performed, and by means of which the borough engineer,

Mr. Bennett, has been able to carry out a very complete system of sewage treatment.

"The third application of the Shone system inspected by me was that at the Houses of Parliament. As Mr. Ault's paper doubtless deals fully with this installation, I will only observe that, although dealing with raw sewage and in confined chambers, there was not the faintest smell nor other objectionable external evidence of the work that was being performed within. What struck me, beyond the regularity and automaticity of working, was the complete control over, or rather the perfect independence of levels which obtains with this system. Beyond this comes the remarkably low working cost, especially as regards the motive power for driving the air-compressors. Atkinson's differential gas engines are employed, and I have not my note-book by me, but I believe I am right in stating that with cannel coal gas at 3*s.* 9*d.* per 1000 feet, the cost is $3\frac{3}{4}d.$ per hour for a 4-horse engine, or less than 1*d.* per horse-power per hour. Seeing then the economy of the Shone system, and the perfect command it gives over differences of level, I cannot conceive—other things being equal—of one more fitted to assist in the disposal of sewage in the face of disadvantages which it would otherwise require a disproportionately heavy outlay to surmount."

Mr. Rogers Field said that Mr. Ault stated in his paper the cost per horse-power of working the gas engines at the Houses of Parliament, and he thought that engineers would be glad to hear from him precisely what he meant by a horse-power in this statement; that is to say, how the horse-power was ascertained. In testing gas engines he (Mr. Field) had obtained very different results when he took the power by the actual quantity of water or sewage pumped to a given height, and when he took it in the way in which the makers generally took it, namely, by indication.

Mr. Stephen H. Terry said that some years ago, thanks to the courtesy of the borough engineer at Eastbourne, he had an opportunity of inspecting the sewage works of that town, and he came to the conclusion that the works had been most efficiently carried out. Although, perhaps, the position of Eastbourne, as regards levels, was such that that town did not especially call for the intervention of the Shone system, still the system worked very well there. He believed that they all knew that Eastbourne was at the present time looked upon as the model of a sanitary town. In December last he had an opportunity of seeing the works in progress at the House of Commons, and on that afternoon he had seen the three ejectors at work. No. 1 was the first ejector to be called into use, and it

received the whole of the sewage of the House of Commons until it was filled; the valve then automatically closed, and the air was turned on, and the whole of the sewage in No. 1, being about 500 gallons, was delivered into the Metropolitan sewer, the sewage in the meantime flowing into No. 2. When No. 2 became full the sewage passed on to No. 3, and in that way the system was made perfectly continuous. Mr. Shone might easily have arranged that instead of having three ejectors one should have done, but in all probability the efficiency of the working would not have been quite so great. The three ejectors were of moderate size, and there was no part of them that was not easily accessible. The system had to deal not only with the sewage, but also with the rainfall. The rainfall of this country was very variable, and running off from a smooth roof like that at the House of Commons a heavy thunderstorm would bring a large quantity of water to be dealt with. In this particular case, arrangements had been provided for dealing with such a quantity. Any one who had had an opportunity of seeing the works in progress, and afterwards seeing them in successful action, could not but think that the right system had been adopted, and a problem solved which had puzzled architects and engineers for a long period.

Mr. W. B. G. Bennett said that he had had nearly five years' daily experience of the working of the Shone system at Southampton. About five years ago the authorities at Southampton commenced to re-drain the greater portion of the low-lying districts of the town, because of the difficulty in obtaining proper velocities in the existing sewers. During heavy rainfalls, previously to the introduction of the Shone system, the sewers became so charged that the basements along the line of the sewers were constantly flooded. The difficulty was to obtain a fall. In order to remedy this defect, with a gravitating system, they would have had to go 20 or 30 feet deep, but instead of doing that they blocked the sewer off from the tide and put down a Shone ejector, and passed the sewage through a 12-inch pipe, discharging above high water. This method had been effectual, and since the alteration none of the basements along the line of sewers had been flooded. The Corporation had found the system so effectual that they had recently adapted it to another purpose, in connection with the clarification of the sewage previously to its discharge at the town quay. About fifteen years ago they built two large reservoirs for storing the sewage during the time of high water, and at ebb tide the crude sewage was allowed to flow out into the Southampton Water. Of course that method could not be permitted now. They had, therefore, put down another ejector in

the reservoirs connecting it with floating arms, the mouths of which were shackled to buoys, which kept them just under the surface of the water to be discharged. Chemicals were added previously, and the sewage was precipitated. The top water, or effluent, was always drawn off through the floating arms into the ejector and was discharged at all states of the tide. Previously to that the sewers were blocked fifteen or sixteen hours out of the twenty-four, but now the ejector enabled them to keep a constant flow. The resulting sludge was run down into a small ejector of 360 gallons capacity, and from that it was transmitted through a 4-inch sealed iron main to the disposal works a mile distant. It was the intention at first to put the sludge into the furnaces of a destructor. They actually burned 20 tons of it, but the farmers had found the sludge to be valuable, and now they came and relieved the works by buying it at half-a-crown a ton. Steam was generated by the heat of the burning ashes in a Fryer's refuse-destructor, passing through the main flue of a large boiler, and was used for compressing air, which was transmitted through an air main from the wharf to the ejectors at the town quay a mile distant. He had been curious to know whether any power was lost in transmission, and had observed the gauge-glass in the engine-room and at the ejectors. One day last week he observed that the reading at the engine-house was 60 lb. per square inch and at the ejectors, a mile away, the reading was a little under 60; so that there seemed to be no loss in transmission. Another great advantage in the ejector system was that it required but very little attention and was easy to adapt to existing systems. Another advantage was that self-cleansing velocities could always be obtained in the sewers. Any number of ejectors could be operated from one station. At Southampton it was impossible to put up buildings for pumps and engines and boilers at the reservoirs on the town quay and lift the sewage by direct pumping. The ejector enabled them to do what was necessary without erecting these buildings which would have shut out the sight of the Southampton Water. He had been curious to find how many tons of the ash-bin contents it was necessary to consume, to obtain sufficient steam for compressing the air for operating the ejectors, and he had found that about 25 tons used in twelve hours would keep up 25 horse-power. This was nearly a ton per horse-power for twelve hours. This consumption had been tested several times at Southampton by other persons besides himself.

Major Lamorock Flower remarked that he saw the Shone system tried first at Wrexham, and he then expressed a favourable opinion of it. He had since seen it at work at

Eastbourne and elsewhere; he was certain that in no instance had it failed to carry out that which Mr. Shone had stated it would accomplish. He thought that the more it was understood by engineers the better it would be appreciated.

Mr. James Atkinson said that his firm had made several engines for Mr. Shone to be used in connection with this system, and he (Mr. Atkinson) had carefully tested them before they were delivered. He had some particulars of the trials which might be interesting. The engines at the Houses of Parliament were 4 nominal horse-power, and on the trial before delivery those engines pumped a quantity of air equivalent to lifting 500 gallons of water 25 feet. The actual horse-power in work on the water would thus (he calculated) be 3·79. The cost of the gas for this work was a little under 4*d.* an hour. He believed that he was perfectly right in saying that these engines were the most economical gas engines which had been made. Some slight improvements had recently been made which enabled them to work more economically still. There was an automatic arrangement for preventing the engines from working when the pumping power was not required; the engines would then burn only from 1½*d.* worth to 2*d.* worth of gas per hour. If the work was intermittent and the engines were compressing air for a fourth of their time the cost per hour was 2⅛*d.* If they were compressing for half the time the cost would be 2¾*d.* per hour; if for three quarters of their time the cost would be 3⅜*d.* per hour; and when they were compressing air the whole time the cost of working would be, as he said before, about 4*d.* an hour, and they would do nearly 4 horse-power actual work on the air.

Mr. William Donaldson said that he first became acquainted with Mr. Shone's ejector at the meeting of the Sanitary Institute at Stafford, and was at once convinced that the pump system worked by transmitted power, actuating automatic machines, would play an important part in sanitary engineering. Since that time he had strongly advocated the system, in co-operation with Mr. Shone, and had demonstrated that pumping by direct application of compressed air in the ejectors could, in the case of low lifts, be done as cheaply as by ordinary pumps, if there was no appreciable loss by leakage. The excessive value of the ratio of the power to the work to be done, adopted by Mr. Shone in his recent installations, he regarded as convincing proof that Mr. Shone had found out by actual practical experience that pumping by compressed air is very costly work. This can only be due to leakage either in the pipes or the ejector valves. The Birmingham Compressed Air Company, in order to guard

against loss by leakage, are going to lay their mains in a covered trench accessible at all points, and special means are to be provided for detecting and stopping leaks. If it is necessary to do this in one case, it is necessary in every case.

Mr. Donaldson affirmed that the credit of first suggesting the sump system was due to Mr. Chadwick and Mr. Phillips, who had proposed that large or flat areas should be divided into small districts, of such a size as to admit of good gradients being obtained for the sewers discharging into the sumps. Mr. Shone had since invented an automatic machine for lifting the sewage by means of compressed air supplied from a central station, and it was for this machine alone that Mr. Shone had any claim to an exclusive right, and not for the sump system. But there were other ways of doing the same thing, both by air and by water. Mr. Baldwin Latham, for instance, had already applied the system at Fryern Barnet, where he used a water-pressure engine, started and stopped automatically by a float, and he (Mr. Donaldson) had himself invented another apparatus which did the work in a similar way to Mr. Shone's, and which could be actuated by either air or water. He did not like the use of a float in a reservoir for causing the automatic action, because sludge would be deposited in the bottom of the reservoir, making its use in a street very objectionable. In his own pump the pipes were connected with the sewer in the same way as with Mr. Shone's ejectors, and the filling of the pump actuated a valve which let in high-pressure water or air. He knew nothing personally about Eastbourne, but would draw attention to one point, viz. that the 600-gallon ejector there had 12-inch delivery pipes, while at the Houses of Parliament the 500-gallon ejector had only 5-inch pipes.*

In the case of Henley, he (Mr. Donaldson) had designed the stations, manholes, ejectors, settling tanks and buildings, everything in fact but the engines and boilers. Those ejectors have a capacity of only 175 gallons and have 5-inch outlets. Mr. Shone seemed quite afraid of designing his apparatus in proportion to the work to be done. He recollected having a strong argument with him upon that point and telling him that he was providing power far in excess of what was required, or that, if it was necessary, he could no longer claim economy of working. The total dead lift at Henley was about 130 feet, which had been divided into two lifts. Provision was made

* Mr. Donaldson afterwards explained that the foreman in charge of the work measured for him the inlet and outlet pipes as 6 inches outside diameter, the inside diameter, therefore, could not have been more than 5 inches. He also scaled as 6-inch outside diameter the pipes shown on the drawing attached to Mr. Shone's pamphlet.

for dealing with the sewage of 6000 people at 30 gallons per head, at the rate of 225 gallons per minute, and at this rate of pumping the friction would, he calculated, make the maximum lift equal to 90 feet, or the total 180 feet, and the air pressure would then have to be 40 lb. on the square inch. The work to be done in lifting the sewage was about 12·3 horse-power. In ordinary installations two 25 indicated horse-power engines, one for a lie-bye would be sufficient, with boilers 5 feet diameter and 20 feet long, whereas the boilers provided were, he was informed by Mr. Hanssen, 6 feet diameter and 26 feet long. To raise the total quantity of sewage only 830 cubic feet of free air were required, or, with 20 per cent. added for possible leakage, 1000 feet. This quantity of free air would be compressed by two compressors 13 inches diameter and 18 inches stroke, running at 60 strokes per minute. The compressors actually provided were 14 inches diameter with 18 inches stroke, capable (as were the engines) of running at 80 strokes a minute, so that there was provision made for nearly two and a half times the quantity of air actually required, the engine power required to do this being fully 60 indicated horse-power. Mr. Shone must have his reasons for making so large provision, which is equal to five times the actual maximum horse-power in work of water lifted. The cost of the installation of an ordinary pumping apparatus for 25 horse-power of actual work would be, he estimated, at the outside 2500*l*. He would ask Mr. Ault to say what the installation did cost, including engines, boilers and buildings.

In the case of the drainage of the Houses of Parliament he observed the same excess of power provided beyond the maximum horse-power in weight of water discharged by the ejectors. He pointed out that a 12-inch pipe had been substituted for what was ordered by the committee, viz. a 3 feet 8 inch × 2 feet 4 inch egg-shaped sewer, lined with white enamelled bricks. The great fault with the old sewer was that the depth varied from 10 feet 6 inches to 4 feet, and there were pockets above which were difficult to ventilate. Those pockets were left still, and therefore, in a sanitary point of view, what had been done was not equivalent to what had been ordered by the committee. There was only one pumping station, and there were four ways in which the pumping might have been done—by compressed air, or by ordinary pumps, using in either case Atkinson's gas engine; by an ordinary steam pumping engine, or by a water engine supplied with high-pressure water from the mains of the Hydraulic Power Company. In his opinion the worst method of all had been adopted. He had reason to believe that the committee who selected it thought that it would

be an automatic arrangement. It was, however, not so, for one man was required by day and another by night to tend it. He was much struck, when he went into the ejector station, at seeing the small size of the delivery pipes, and still more so when he found that the 500-gallon ejector had a delivery of the same size as the 350-gallon ejector. He had been under the impression that the ejectors had been designed to fill and empty in a minute. Mr. Shone seemed to think that the quantity that could be discharged per minute depended upon the size of the ejector itself; but that had really very little to do with it. The quantity that could be discharged depended upon the size of the inlet and outlet pipes and the power expended in producing velocity. The 500-gallon ejector was emptied in about three-quarters of a minute. That meant with a 5-inch pipe a velocity of 14 feet per second. Allowing for the resistance due to friction in the pipes and valves, he did not think that velocity could be produced with a head of less than 6 feet, and he therefore considered that there must then have been a total head of about 16 feet to work against. With regard to the gas engines, he would point out that each gave out 4 horse-power measured by a brake, or, adding 25 per cent. for engine friction, 5 horse-power indicated. The four engines would therefore be equal to 20 horse-power. The work done in weight of water raised, with 10 lb. pressure of air, was less than 6 horse-power; the power provided was therefore three and one-third times the work to be done in weight of water lifted. Mr. Shone would, he felt sure, admit that an ordinary 12 horse-power engine indicated, would do 6 horse-power work in weight of water raised.

Mr. Shone, in a paper written by him, had alluded to the reflux valve connected with the 12-inch pipe at the Houses of Parliament as a means of dealing with the storm water, while Mr. Ault, in his paper to-night, had alluded to it as a means of dealing with the dry-weather sewage. Which of these statements is correct, is not a point of importance; it is sufficient to know that this 12-inch pipe is the only storm-water overflow provided. The total area occupied by the Houses of Parliament is a little under 10 acres, of which 8 acres discharge their rainfall into the sewer. He was told that in storms as much as $1\frac{1}{2}$ inch of rain had been known to fall in half an hour, but, taking it at only 1 inch per hour, that would mean 180,000 gallons on the 8 acres. This was equivalent to 3000 gallons a minute, and the ejectors could only deal with 1000. What was to be done with the remaining 2000 gallons? The whole of this surplus 2000 gallons would have to pass through the 12-inch outlet pipe and to lift the reflux valve, which is unbalanced. The

velocity would be 7 feet per second and the equivalent head about 3 feet. The whole of the 3000 gallons has to be conveyed through the 12-inch pipe to the ejector station, and therefore the maximum velocity would be 10 feet 6 inches per second. It is impossible to calculate accurately the hydraulic gradient from the sump to the beginning of the pipe, because the velocity varies. The head due to friction would probably lie between that due to 10 feet 6 inches per second for half the length of the pipe (about 500 feet), viz. 14 feet, and that due to a velocity of 5 feet 3 inches for the whole length, viz. 10 feet. Taking 12 feet as the mean of these, he was quite sure it would not be less than that.

It was stated in the Reports that, when the sewers were connected directly with the Thames, the cellars of the Houses of Parliament were flooded during all high floods, and pumping plant was fixed permanently to discharge the overflow water. After they were connected with the Metropolitan main sewer there was still some flooding, but not enough to require the use of the pumping plant. At that time there was a balanced reflux valve to be raised of the full size of the existing sewer. He therefore thought it might fairly be assumed that there would not be more than 6 inches difference of level on the surface of the sewage above and below the reflux valve. If that caused flooding, what would be the case when there was 3 feet difference, and the surface of the sewage at the Speaker's Green was 2 feet 6 inches higher than when the sewer was connected directly with the Metropolitan main sewer? From the Speaker's Green to the Victoria Tower, the rise in the surface of the sewage, with 1 inch of rainfall in an hour, would be about 12 feet, so that at the Victoria Tower the surface would be 15 feet higher than in the Metropolitan sewer, and he ventured to think that during a heavy storm the condition would be worse than it was during a high flood at the time when the sewer was connected directly with the river. The existing reflux valves ought to have been retained, and the 3 feet 8 inches by 2 feet 4 inches sewer ordered by the committee constructed. He believed that, had either of the other three methods been adopted, the pumping installation, including the underground chamber, might have been provided for about 1500*l*. He should like to know from Mr. Ault what the actual installation had cost, in air compressors, pipes, receivers and ejectors alone. Mr. Shone has stated in the concluding part of his pamphlet addressed to the Members of the House that the whole cost had been a little over 11,000*l*. The estimate laid before the Committee was 9600*l*., and that included the egg-shaped sewer, to be lined with white enamelled

bricks, for which the 12-inch pipe had been substituted. He (Mr. Donaldson) thought that at least 600*l.* must have been saved by this alteration, so that the actual cost exceeded the estimate by over 2000*l.* He was sure that the whole work might have been efficiently carried out, including the egg-shaped sewer, for less than 5000*l.*

Reverting to Henley, he should like to ask what loss of pressure, if any, there was between the engine-house and the end of the sewer, for he had no doubt that Mr. Shone had made a thorough test of the pressures.

He was much surprised that Mr. Shone had not selected Beaumaris as a typical illustration of his system, as he made a special point of the applicabilities of his system to the drainage of seaside towns with long level esplanades, such as exist at Beaumaris, which has been entirely drained on his system, while at Eastbourne there was only a partial application of it. He understood that the works at Beaumaris were completed nearly twelve months ago, and should like to know whether any house drains had been connected with the main sewers, and, if not, why not?

Mr. W. V. Graham said that it was difficult to understand the advantage of adopting the Shone system unless Mr. Shone could give them the instance of a town which he considered badly drained, and which could be improved by the application of his system. He (Mr. Graham) thought that, so far as they had heard to-night, Mr. Shone's plan could not be called a system at all. Engineers knew perfectly well that it had been possible for a long time to make sewers which, if laid at proper gradients, would keep themselves clean, and he did not think that Mr. Shone could offer anything more. By gas engines or other means it was possible to drain towns in small areas, and so avoid deep sewers and heavy pumping. He should like to hear from Mr. Shone what he claimed beyond the ejector, which was simply an application of the transmission of power by means of compressed air.

Mr. Shone, referring to the remarks of the last speaker, said that to enter into the details of any particular town, and explain how his system could be applied to the sewage of that place, would engage the attention of the meeting too long. He was rather surprised that the speaker had not posted himself up somewhat in the literature which was current on the subject. The object of the system was to enable an engineer to lay down sewers which would be effectual in carrying both the minimum and the maximum volume of sewage to its destination, without causing any nuisance en route to the outfall. The pneumatic ejector could be placed under a street, and so

the town authorities would not be required to buy land for a pumping station. He had been rather taken aback to hear his old friend, Mr. Donaldson, expatiate as he had done. Ever since the time that he first met him until very recently, Mr. Donaldson had been one of the foremost in holding up this system as the perfection of systems. Mr. Donaldson had co-operated with him with reference to Henley-on-Thames. He had entrusted the draughting out of the work to Mr. Donaldson, and when he did so, he considered him competent. But Mr. Donaldson, like himself, was not perfect. He (Mr. Donaldson) had been very wishful to try his hand at designing the ejectors for Henley, and he did so. He (Mr. Shone) was afraid the fault with those ejectors would be that their bottoms would gradually silt up, and that they would have to be cleansed occasionally, whereas, in the form of ejector shown in Fig. 1, any heavy matter would go down to the bottom of the apparatus and would consequently be ejected first of all. Mr. Donaldson had nothing whatever to do with designing the engines for Henley. With regard to the economics of the ejecting system, as compared with pumping, it really was most difficult to get at them because the quantity of sewage gravitating to the ejector station was very irregular, and could not be recorded accurately without a great deal of trouble and making a most complicated series of tests; and after getting at all the information, it would be of little practical value, for, whether the efficiency of the ejector is high or low, the fuel consumption, from the very nature of the work to be done, would not be affected for or against the system. Mr. Donaldson had dilated upon the arrangement of the ejector system at the Houses of Parliament, but he had mis-stated the facts to the meeting. He had told them that the 12-inch iron pipe sewer was very inferior to the egg-shaped sewer suggested in the Report of the Committee, because it reduced the reservoir capacity. As a matter of fact, however, the reservoir capacity in the original sewer amounted to about 18,265 cubic feet, and the arrangement recommended by the committee would have reduced it to about 5336 cubic feet, while the plan actually adopted retained 15,263 cubic feet, that is, 84 per cent. of the original capacity was retained by his (Mr. Shone's) arrangement, but that proposed, with the egg-shaped sewer within the old sewer, would only have retained 29 per cent. as storage for rainfall in case of need. The committee, however, had had the matter explained to them, and were perfectly satisfied that the present arrangement was better than the original proposal. From what had been said by Mr. Donaldson it might be imagined that the sewer at the House of Commons was still a foul one. He

(Mr. Shone) could assure the meeting that the air of the big old sewer, which had been converted for the most part into a subway, was sweeter than the air of the room in which they were then met. Indeed, one of the members of the committee had suggested it as a lounge for members to retire into, because of the salubrity of the air. There was no connection between the large space or subway and the new 12-inch pipe sewer, as might be seen by the drawing showing the way in which the connections were made. A constant current of air also traversed the iron pipe itself. When the plant was designed for the Houses of Parliament he certainly thought that the quantity of sewage would be as much as 150 gallons per minute when the House was sitting, but instead of that they got only from 40 to 50 gallons per minute. He had also anticipated a heavy rainfall. Sir Robert Rawlinson gave evidence before the Select Committee which decided in favour of the present plan, and his opinion was that if pumping power, or ejecting power, as the case might be, were provided, which, when duplicated and both sets were at work, would deal with 400 gallons per minute, as a maximum, there would be a superabundance of power. He (Mr. Shone) thought, with all due deference to Mr. Donaldson, that Sir Robert Rawlinson's evidence was as good as his on this point. Mr. Donaldson admitted that, in spite of the alleged bad contrivances, they could deal with 1000 gallons per minute. He (Mr. Shone) was quite satisfied to be able to deal with that quantity. Mr. Donaldson was mistaken as to the sizes of the pipes. The internal diameter of the inlet was 6 inches, and that of the delivery was the same, and therefore the calculations based on 5-inch pipes were erroneous. As to the rainfall, he assured Mr. Donaldson that he was utterly wrong in taking one inch rainfall per hour. Sir Joseph Bazalgette had only provided in the Metropolitan main sewers for about a quarter of an inch of rainfall in 24 hours. One inch of rainfall in 24 hours, plus the sewage, would only give about 230 gallons per minute off eight acres, which was said to be the area drained. There was another important point which Mr. Donaldson would surely appreciate because he was well up in it. Supposing that they had an ordinary pump to do the work and there was just work enough for one horse-power to overcome friction. If the velocity to be given to the sewage were doubled, then the head must be quadrupled. That is to say, they must have four times the frictional head to get double the velocity, and they must have eight times the power to propel the fluid, because the volume would be doubled. In other words, if one horse-power was needed to overcome the frictional head at a given

velocity, eight horse-power would be required for working at double the velocity. The ejectors at the Palace propel the sewage, when the dry-weather flow obtains, at a velocity of from 12 to 15 feet per second. Theoretically this results in a waste of power, but practically it has no appreciable effect upon the cost of working from day to day. That was a matter of fact. The quantity, from even a small rainfall, proceeded to the station very rapidly, so that instead of having 50 gallons per minute they could take, as Mr. Donaldson said, 1000 gallons per minute. He (Mr. Shone) would like to see the pumping engine which would be prepared as the gas engines and ejectors combined were prepared to tackle with the same facility 50 gallons and 1000 gallons. Mr. Atkinson had shown that by the aid of his ingenious gas-engine air-compressor they could get an actual horse-power in water or sewage lifted for 1*d.* per hour. He should like to see a pump that could compete with that. He was satisfied with the result, and he had it on the authority of Sir Henry Roscoe, the chairman, that the committee were also perfectly satisfied.

Mr. Peregrine Birch said that Mr. Shone would not and could not lay claim to having invented the "separate system."

Mr. Shone: Certainly not.

Mr. Birch said that they had heard a good deal in the paper about "separate system," but every engineer for the last twenty years had laid out his sewers with a view to avoiding deposits of road detritus, and to reducing his sewers to practicable size and obtaining self-cleansing gradients. Therefore there was no credit due to Mr. Shone for self-cleansing sewers. What Mr. Shone had really brought forward was one of many machines which would pump small quantities of sewage to small heights. He had wished Mr. Shone to give them the actual lifts in each of the cases. By the actual lifts he meant the difference of level between the low-level sewer and the high-level sewer; not the difference between the ejector (which was 8 or 9 feet below the low-level sewer) and the high-level sewer, because that had nothing to do with the matter. In the case of the Houses of Parliament Mr. Shone, having a normal lift to deal with of about 3 or 4 feet, at once, by means of an uneconomical unscientific machine, increased the lift from 4 feet to 12 feet. Even supposing that the lift of 12 feet was unavoidable, then to place the engine 200 yards away from the machine, and put two cast-iron mains the whole length of the building to carry the compressed air, was an uneconomic and unscientific thing to do; and was sufficient reason for requiring all the figures and the fullest opportunity of discussing and considering them. He, for one, thought it a great mistake. He quite agreed with

Mr. Shone in putting the 12-inch cast-iron pipe to carry the sewage from one end of the building to the other. He was perfectly right in that, and nothing could have been better; but he thought that Mr. Shone might have put his gas engines under the Speaker's Green just as well as at the other end of the building and more economically. He considered that the value of the paper and of the discussion was very materially impaired by the absence of the figures which would have enabled the meeting to deal with the subject. Mr. Shone did not do himself justice in saying that to collect the necessary figures was too difficult for him. He might have given the fine-weather lift and the fine-weather flow, and he might have told them that the average lift was about $3\frac{1}{2}$ feet.

Mr. SHONE: $12\frac{1}{2}$ feet minimum, and up to 25 feet in some states of the Metropolitan sewer.

Mr. BIRCH said that Mr. Shone did not mean the same thing by "lift" as he (Mr. Birch) meant. Mr. Shone included the 8 or 10 feet voluntarily added to the net lift.

Mr. SHONE asked Mr. Birch whether, if he had a pump, he would not require a well to pump from?

Mr. BIRCH said that he quite admitted that Mr. Shone could not have got the ejector into a smaller hole than he had used; but he thought that he had added unreasonably and unnecessarily to the work which he had to do, and that, having so increased the work to be done, he had not done it economically.

Mr. SHONE remarked that, although theoretically every foot of drop into a sump meant waste of power, practically it was not so, and the cost of running the gas engines would not be increased by the drop into the ejector.

Mr. W. P. MORISON said the author had given the cost of the installation of the Henley sewage works at 18,000*l*. Could he tell them what rate in the pound that represented? He believed that it was always usual and useful in estimates for such works, to state what ratable property the cost had to be charged upon, and what rate in the pound it represented. He also wished to ask the author what was the use of the vertical standpipe next the siphon in the flushing tank?

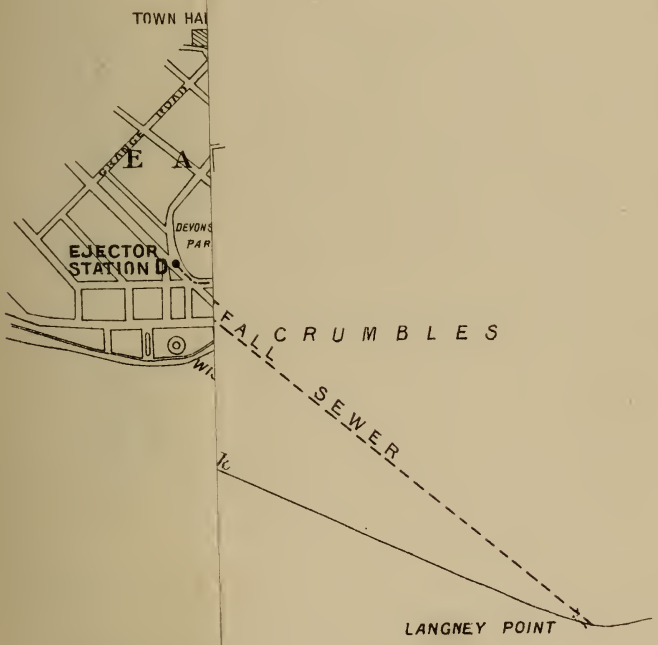
Mr. AULT, in replying on the discussion, said that many of the points raised had been already answered. Mr. Donaldson had mentioned the pockets on the main sewer, which, he said, remained. The pockets did remain, but they had been covered over with manholes, which had been pierced for ventilation, so that there was no stagnant air whatever throughout the whole of the old sewer, which was now used as a subway. With regard to what Mr. Birch had said as to the extra depth, Mr. Shone set the depth of the ejector below the inlet of the sewage against

the friction of the moving parts in ordinary pumping engines. Considering the problem which had to be dealt with, that of raising sewage in quantities which varied extremely as compared with ordinary pumping, and of raising that sewage without having any reservoirs or any stagnant portion, he believed that the ejector would be found to be economical compared with other machines, notwithstanding the extra depth or lift which was given to the sewage by the artificial means employed. That being his opinion, he certainly resisted the expression which Mr. Birch applied to the ejector, that it was "uneconomical and unscientific." With regard to having two compressed air-mains throughout the basement, he might say that they were placed there in duplicate in deference to the wish of the committee. The standpipe in the flushing tank was put there for ventilation purposes, to allow the entrance of air into the sewer, and had nothing to do with the action of the flushing-tank.

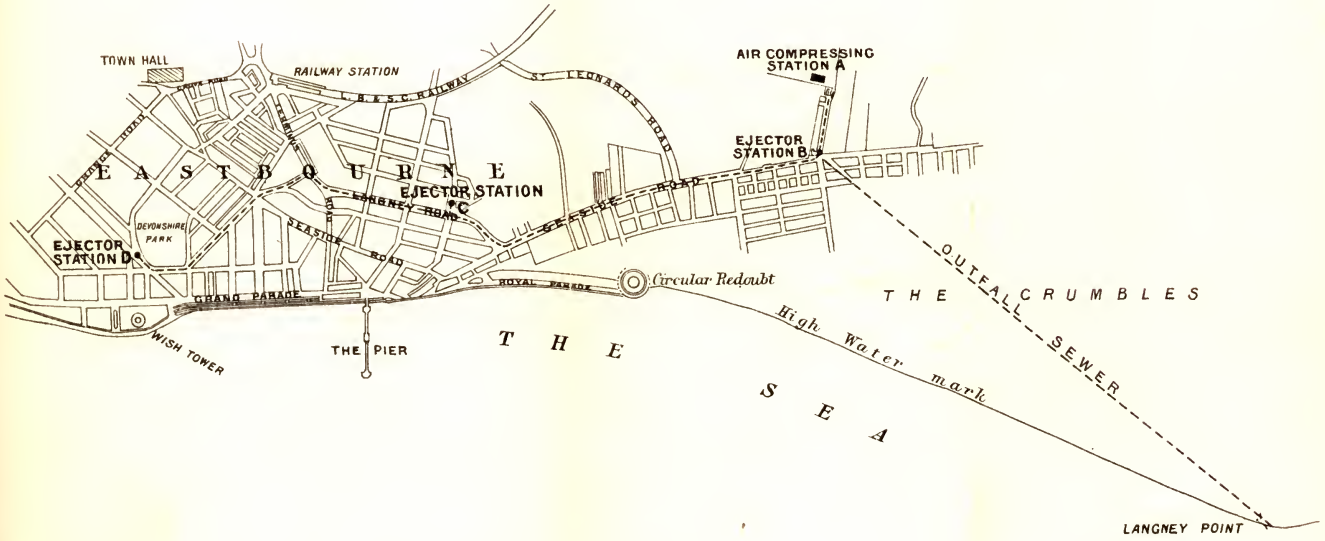
Mr. DONALDSON asked whether Mr. Ault refused to tell him the cost of the installation at Henley, and did he refuse to give him information about Beaumaris, as to whether the system was in operation, and if not, why not?

Mr. AULT said that he had given the total cost of the works at Henley. He had not got the detailed figures with him. As to Beaumaris, the works were only commenced a little over twelve months ago.

Mr. SHONE said that the Henley connections were being made as rapidly as possible. The initial cost of the works, both at Henley-on-Thames and Beaumaris, was practically what it was estimated to be in the first instance: and, so far as his experience of the working expenses of the steam-engine air-compressors at Henley, and of the gas-engine air-compressors at Beaumaris, enabled him to judge, he was pleased to say that they did not, and would not, exceed the preliminary estimates submitted by him to the corporations of those towns.

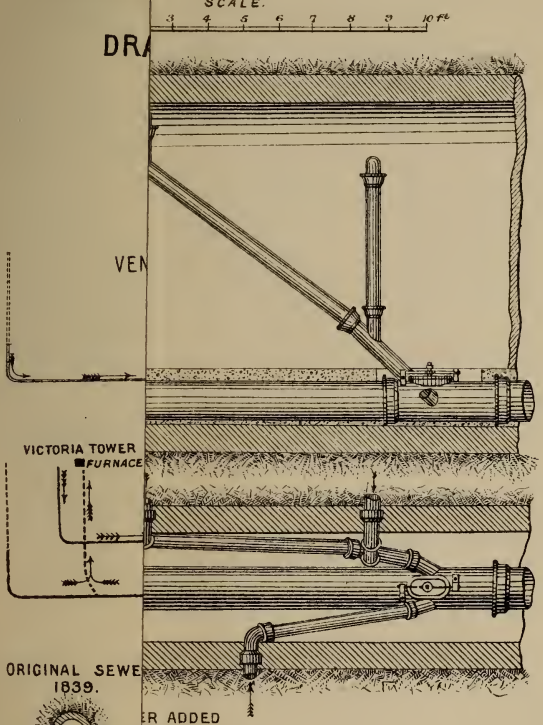

TOWN HA
E A
DEVONS
PAR
EJECTOR
STATION D.
FALCRUMBLES
SEWER
LANGNEY POINT

EASTBOURNE DRAINAGE & SEWERAGE



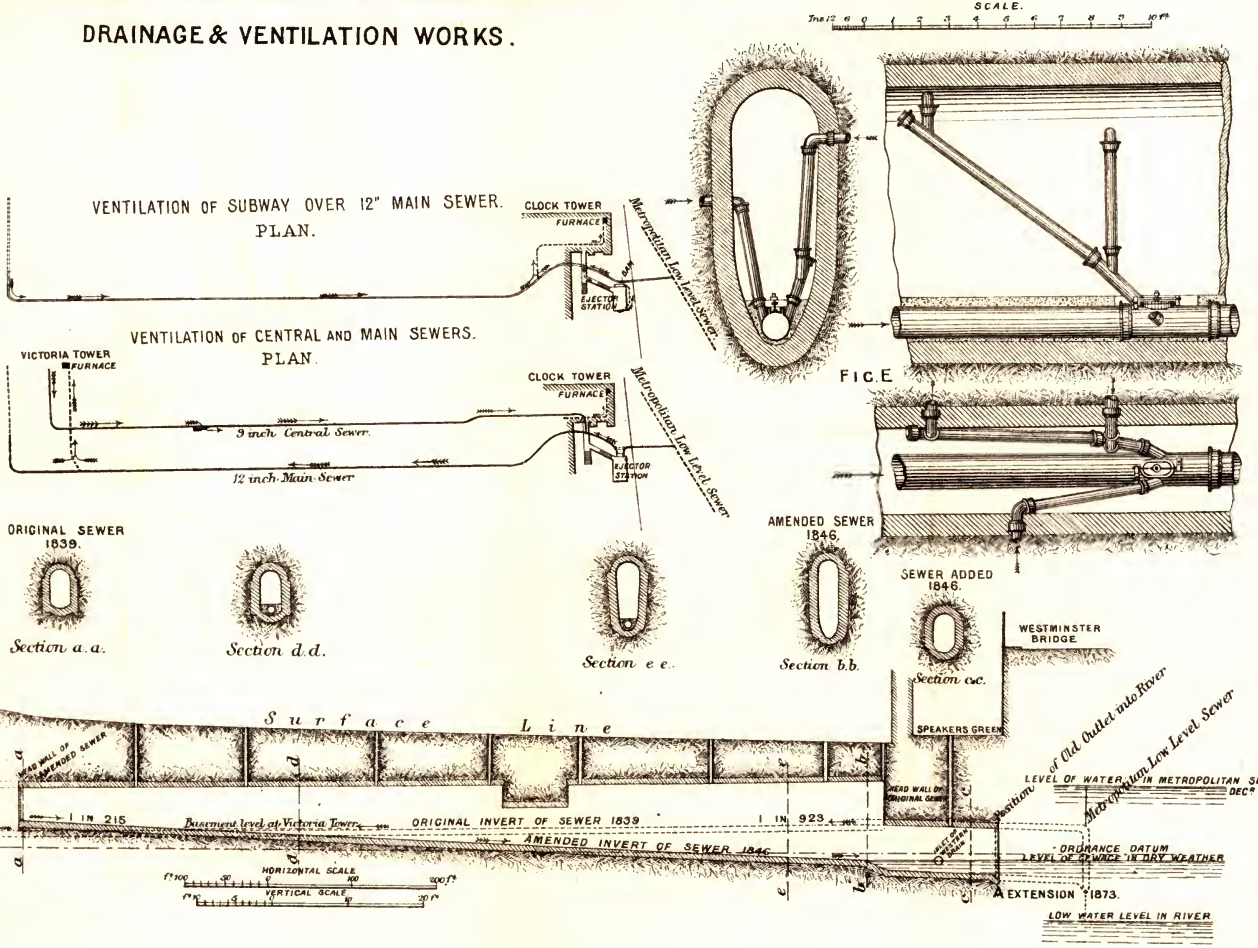
HOUSE

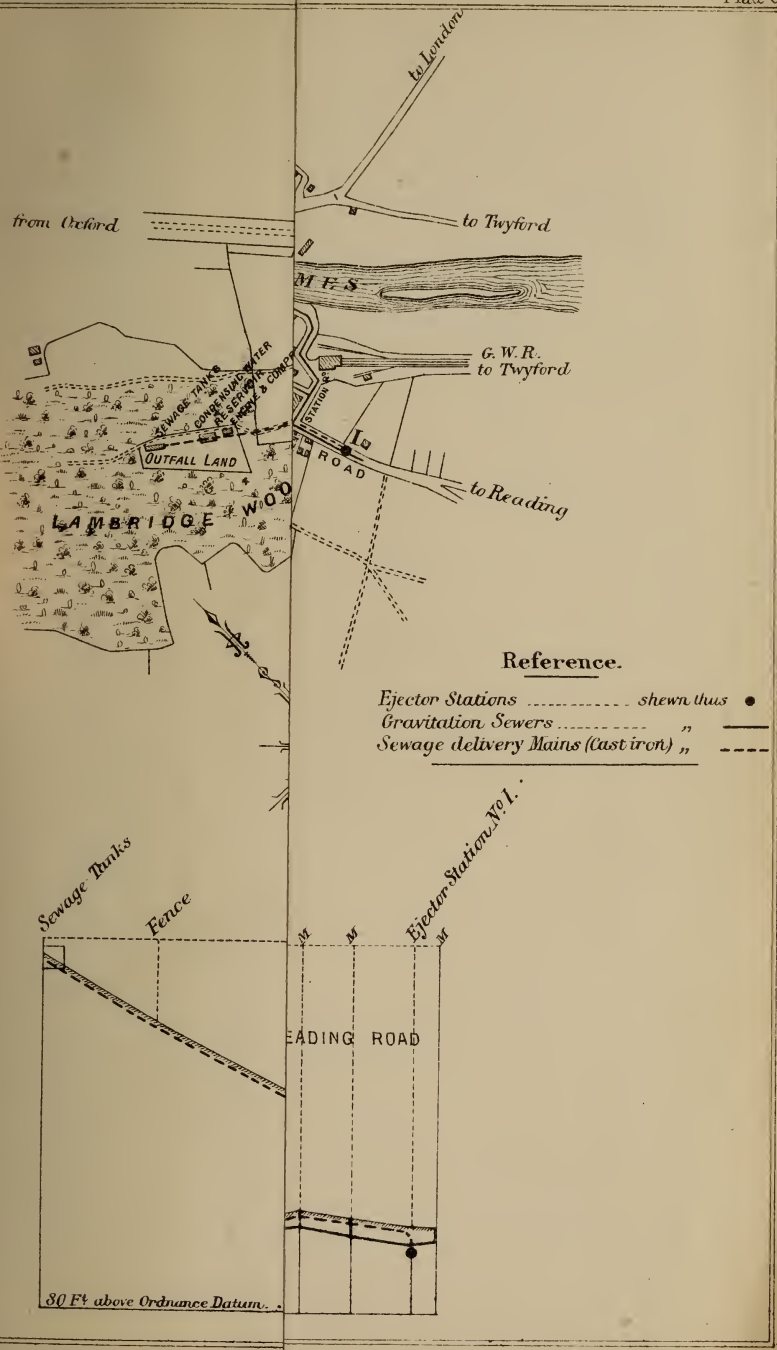
DRA


SCALE.
3 4 5 6 7 8 9 10 Ft
VEN
VICTORIA TOWER
FURNACE
ORIGINAL SEWE
1839.
ER ADDED
846.
Section a.a.
tion c.c.
WESTMINSTER
BRIDGE
ABINGDON STREET
EAKERS GREEN
HEAD WALL OF
AMENDED SEWER
IGINAL SEWER
1 IN 2
ORDNANCE DATUM
Position of Old Outlet into River
Metropolitan Low Level Sewer
LEVEL OF WATER IN METROPOLITAN SEWER
DEC^R 15TH 1886.
ORDNANCE DATUM
LEVEL OF SEWAGE IN DRY WEATHER
EXTENSION 1873.
LOW WATER LEVEL IN RIVER

HOUSES OF PARLIAMENT WESTMINSTER.

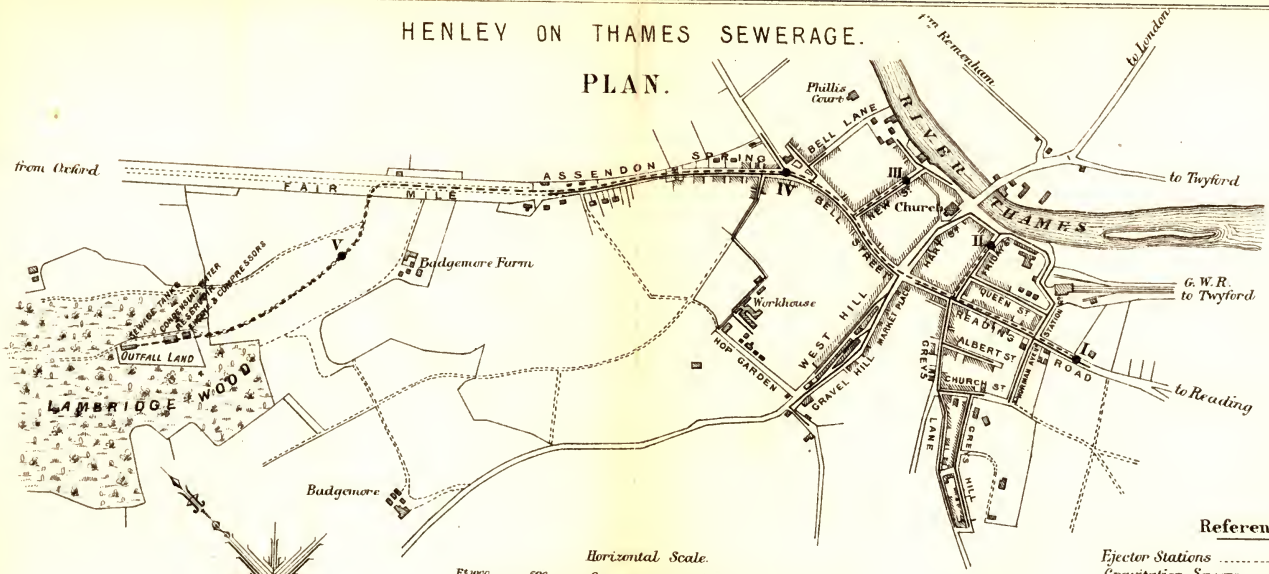
DRAINAGE & VENTILATION WORKS.




to London
from Oxford
to Twyford
M & S
G. W. R.
to Twyford
SEWAGE TANKS
CONDENSING WATER RESERVOIR
ENGINE & COMPTS
STATION
OUTFALL LAND
ROAD
to Reading
LAMBRIDGE WOO
Reference.
Ejector Stations ..... shewn thus ●
Gravitation Sewers ..... „ ——
Sewage delivery Mains (Cast iron) „ - - - -
Sewage Tanks
Fence
Ejector Station No 1.
M
M
M
EADING ROAD
80 Ft above Ordnance Datum.

HENLEY ON THAMES SEWERAGE.

PLAN.



Horizontal Scale.

Ft 1000 500 0 1000 2000 Ft

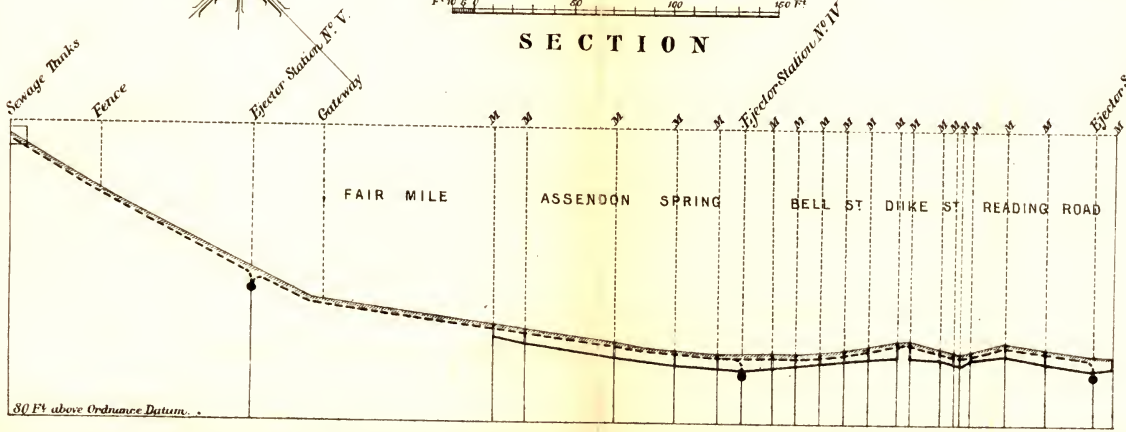
Vertical Scale.

Ft 10 0 50 100 150 Ft

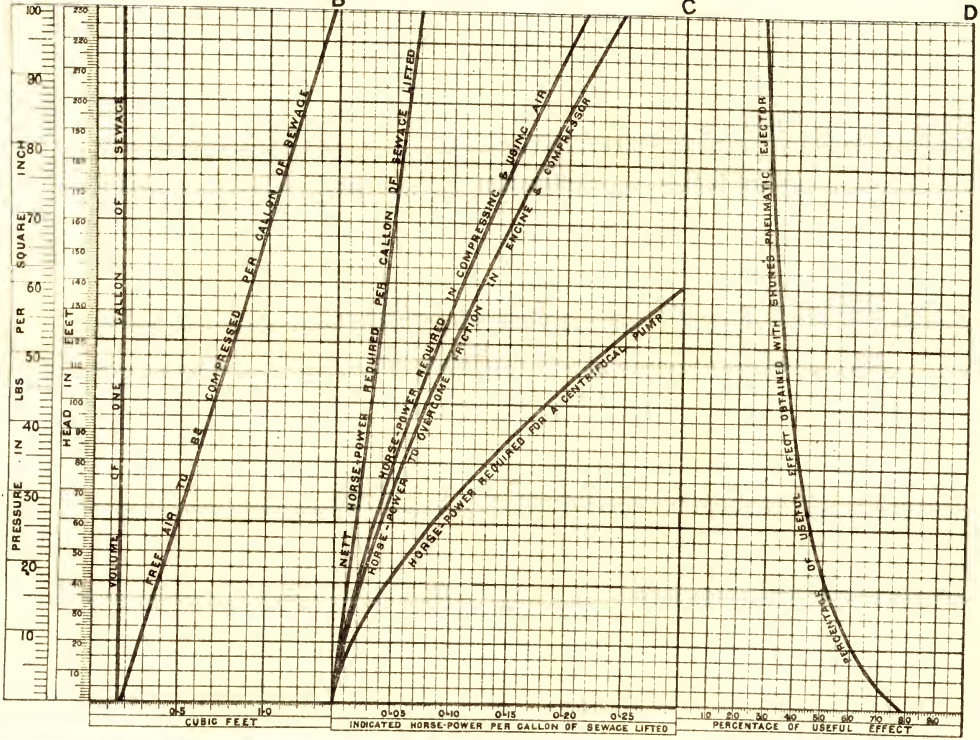
Reference.

Ejector Stations ..... shewn thus ●
Gravitation Sewers ..... " ——
Sewage delivery Mains (Cast iron) " ----

SECTION



A
D
PRESSURE IN LBS PER SQUARE INCH
HEAD IN FEET
VOLUME OF ONE GALLON OF SEWAGE
FREE AIR
PERCENTAGE OF USEFUL EFFECT OBTAINED WITH SHUNES PNEUMATIC EJECTOR
PERCENTAGE OF USEFUL EFFECT


A
B
C
D
PRESSURE IN LBS PER SQUARE INCH
HEAD IN FEET
VOLUME OF FREE AIR TO BE COMPRESSED PER GALLON OF SEWAGE
VOLUME OF ONE GALLON OF SEWAGE
INDICATED HORSE-POWER REQUIRED PER GALLON OF SEWAGE LIFTED
HORSE-POWER REQUIRED IN COMPRESSING & USING AIR
HORSE-POWER TO OVERCOME FRICTION IN AIR ENGINE & COMPRESSOR
HORSE-POWER REQUIRED FOR A CENTRIFUGAL PUMP
APPROXIMATE % OF USEFUL EFFECT OBTAINED WITH STUNED PNEUMATIC EJECTOR
CUBIC FEET
INDICATED HORSE-POWER PER GALLON OF SEWAGE LIFTED
PERCENTAGE OF USEFUL EFFECT

May 2nd, 1887.

HENRY ROBINSON, PRESIDENT, IN THE CHAIR.

REFRIGERATING MACHINERY ON BOARD SHIP.

BY T. B. LIGHTFOOT, M.I.C.E.

So far as the author knows, the earliest vessels in which refrigerating machines were applied were the *Paraguay* and *Frigorifique*, which were employed in carrying mutton and beef from the River Plate to Havre. The first was fitted with refrigerators on the Carré, or ammonia absorption system, and brought over as much as 20,000 carcases, or about 500 tons of mutton at a time. The *Frigorifique* was fitted with compression machines on the Tellier system, in which heat was abstracted by the evaporation of methylic ether, the vapour being subsequently condensed and used over again; and carried about 100 tons of meat. Both these vessels made several very successful trips and landed their cargoes in good condition, but neither the machines nor their mode of application were considered suitable for marine purposes, and their use was discontinued and has never since been revived. It is not proposed therefore to deal further with these early applications. A description of the Carré and Tellier machines will be found in a paper on "Refrigerating and Ice-making Machinery and Appliances," read by the author before the Institution of Mechanical Engineers in May 1886.

At the present time it may be said that the only machinery in use on board ship for refrigerating purposes is that in which heat is eliminated by the successive compression, cooling when under compression, and subsequent expansion in the performance of work of ordinary atmospheric air. This principle, though well known to scientific men since the development of the mechanical theory of heat by Dr. Joule, and notwithstanding the fact that air refrigerating machines were at work in America in 1845, and in this country in 1856, only began to attract the serious consideration of practical engineers about the year 1870. It was not, however, until some years later that the subject became of anything like general interest. At this time the price of home-grown meat being exceedingly

high, attention was directed to means for calling into requisition the vast stocks of our colonies, and the result was the development of an entirely new trade, which however disastrous to growers at home, has been largely instrumental in bringing the prices of both beef and mutton, but especially of the latter, to their present low level.

The theory of air refrigerating machines has been so fully dealt with in various previous papers and publications by the author, that it is only proposed to refer to it briefly in the present instance. The intrinsic energy of a gas, or its capacity for performing work, is measured by the amount of work it is capable of performing without receiving external assistance. Hence, as heat is the sole cause of energy, the temperature of a gas is the measure of its capacity for performing work. Increase of pressure under constant temperature imparts no additional energy, but merely places a gas in such a condition relatively to some other pressure or resistance as to enable advantage to be taken of its intrinsic energy by expansion. It follows, therefore, that the performance of work by a gas must always be accompanied by an equivalent reduction in temperature, unless an addition of energy be received from without, while, conversely, the performance of work upon a gas must produce a rise in temperature. The laws relating to pressure, volume, and temperature of perfect gases are known as the gaseous laws of Boyle and Charles, and are expressed by stating that $\frac{v\,p}{t}$ remains constant for the same gas, v being volume, p absolute pressure, and t absolute temperature. In the case of change in volume and pressure under constant temperature, the product of the absolute pressure and volume is constant, or in other words the volume varies inversely as the pressure. This is what occurs in isothermal compression and expansion, the curve of which is a hyperbola, and in order to attain this it is necessary in the one case that the heat equivalent of the mechanical work expended during compression should be communicated to some external body, and in the other case that the heat equivalent of the work performed during expansion should be supplied from without.

If all the heat developed during compression be retained by the gas without loss, compression is then called adiabatic, and the relations between temperature, volume, and pressure are as follows :—

$$\frac{t}{t_1} = \left(\frac{v_1}{v}\right)^{\gamma - 1} = \left(\frac{p}{p_1}\right)^{\frac{\gamma - 1}{\gamma}}$$

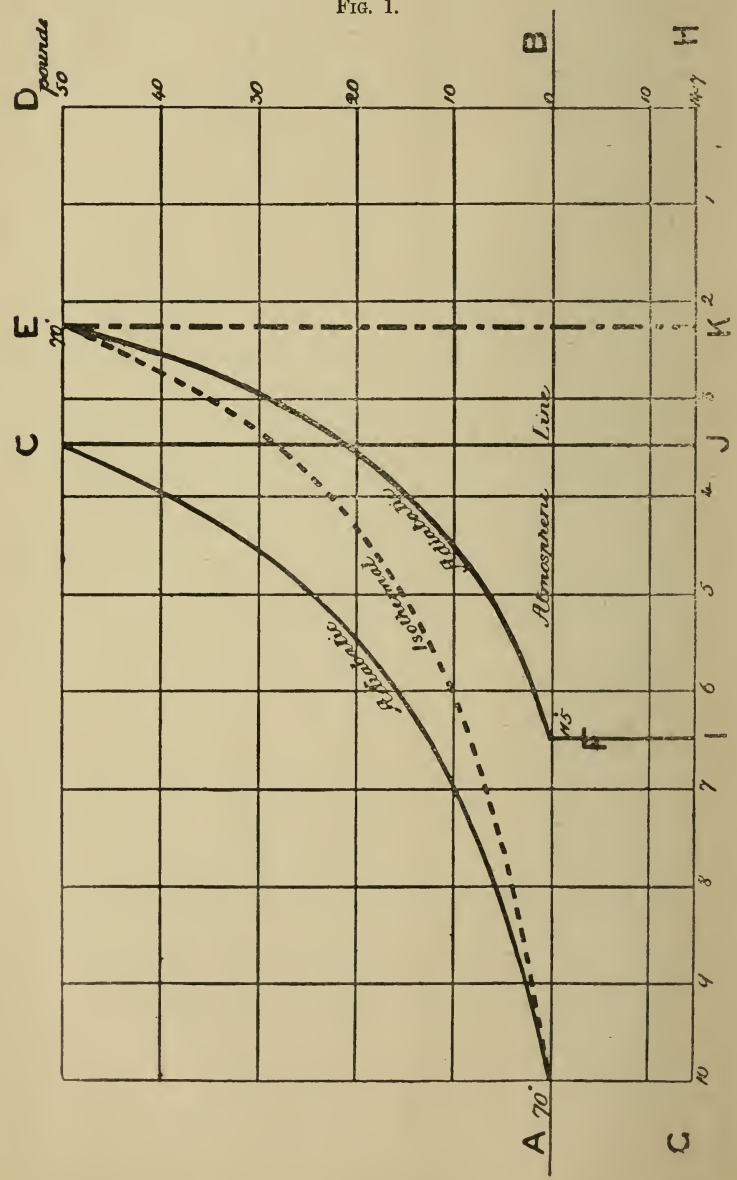
where t_1, v_1, and p_1 denote absolute temperature, volume, and absolute pressure before compression, and t, v, and p those after compression, while γ is the ratio of the specific heat under constant pressure to that with constant volume. During adiabatic expansion changes occur the exact converse of those just referred to, the whole of the mechanical work being performed at the expense of the energy of the gas, whose temperature is therefore reduced to an extent measured by the thermal equivalent of the work done. The same relations as given for adiabatic compression hold good for adiabatic expansion, t, v, and p being the absolute temperature, volume, and absolute pressure before expansion, and t_1, v_1, and p_1 those after expansion. In this connection it should be stated that the term adiabatic expansion is used as implying work performed against the greatest possible resistance. Should the resistance be less than the pressure due to the gas, it necessarily follows that the conversion of heat into work is less than if the greatest possible resistance had been overcome. This was proved experimentally by Joule by means of a couple of vessels, one filled with air under pressure and the other exhausted. On opening a cock between the two, the pressure became equalised, but the temperature was the same as at the commencement.

In Fig. 1 are shown the various curves for the isothermal and adiabatic compression and expansion of dry air.

If ordinary atmospheric air merely consisted of oxygen and nitrogen, the foregoing considerations would be all that are needed in connection with the abstract theory of air refrigerating machines. There is, however, always present a considerable amount of aqueous vapour, which often exists in sufficient quantity to fully saturate the air at its ordinary temperatures and pressures. It is necessary, therefore, to consider how this vapour behaves in relation to the mechanical refrigeration of air. The elastic force of aqueous vapour in contact with its own liquid is a function of the temperature, and increases rapidly as temperature rises. It is the same whether a given volume is occupied by vapour alone or by a mixture of vapour and air, and it is independent of the pressure of the air. The total pressure of the mixture is however different, being the sum of the vapour pressure and that of the air. It follows, therefore, that a volume of saturated air at any given temperature can only hold one definite amount of vapour, and if from any cause additional moisture is present, it must take the form of water, as fog or mist. On the other hand, any less amount than that required to produce saturation may be present, but in this case a reduction of temperature will increase relative humidity until finally saturation or the

"dew-point" is reached, after which further cooling will be accompanied by partial liquefaction. The same result may be brought about by reducing the volume of a partially saturated

FIG. 1.



mixture of air and vapour, provided there is not at the same time an increase of temperature sufficient to produce such a rise in elastic force as to enable the vapour to occupy the new volume without liquefaction. Increase of pressure, therefore, under constant temperature decreases the capacity of a given weight of air for holding vapour in solution.

In air refrigerating machines the result of this varying vapour capacity is to cause a separation of moisture during the cooling of the compressed air, as well as during expansion. The coolers have therefore to condense and remove this surplus moisture as well as to abstract the heat from the compressed air, while in expansion allowance must be made for the heat liberated during liquefaction and freezing of the vapour, as well as for the mechanical effects produced by the formation of snow. In some refrigerating machines advantage has been taken of the varying vapour capacity to cause a further separation of moisture by subjecting the compressed air, after cooling by water, to the action of cold, derived either direct from the air as it is discharged from the machine, or from the spent air issuing from the chamber in which the cold has been utilised. This will be further referred to hereafter.

Passing now to the practical application of the foregoing, a cold-air machine or dry-air refrigerator consists of a compressor, in which air is compressed, generally to about 50 lb. per square inch; a cooler, in which the heat of compression is abstracted by the action of cold water and where vapour is condensed from the air and deposited as water; sometimes of an interchanger, in which the compressed air is still further cooled; and an expansion cylinder, in which the cold compressed air is expanded down to its original pressure. In some cases water injection has been applied during compression, but this has not been altogether successful in practice, and at the present time the author believes that all new machines are made with surface cooling. The difference between the power expended in compression and that given back in expansion, plus the friction of the apparatus, must be applied by a steam engine working direct on to the shaft, as is the usual method, or in some other convenient way.

Having now briefly set forth some of the principal considerations in regard to the construction of air refrigerating machines, it will perhaps be convenient to glance at the chief points in the history of their development. In 1845, Dr. Gorrie, an American, made ice by a cold-air machine in New Orleans. Some years later one of Dr. Gorrie's machines was at work in Camden Town, where it attracted considerable attention, and, as is probably known to many Members, was examined and

reported on by the late Sir W. Siemens, whose report shows how thoroughly that distinguished man was acquainted with the theory of thermodynamics even at that comparatively early period. At this time Siemens protected the invention known as the interchanger, an apparatus by means of which it was intended to utilise the waste cold of the spent air in lowering the temperature of the compressed air before expansion, below that to which it could be brought by ordinary cooling water. In 1862 Mr. A. C. Kirk produced his well-known ice-making machine, of which a full description was given in a paper read before the Institution of Civil Engineers in 1874. About the year 1869 Windhausen and Nehrlich in Germany brought out several improvements in the details of compressed air machines, chiefly in regard to the cooling of the air after compression. Windhausen in one of his patents suggested an interchanger essentially similar to that previously invented by Siemens. A number of Windhausen's machines were made and put into operation with fairly good results in various parts of Europe and in North and South America. Their principal objection, and one which interfered with their continuous working, was that owing to a bad construction of the exhaust valves of expansion cylinder, the snow, which in all cold-air machines is formed during expansion, was not freely discharged, and in course of a few hours' working it caused so great an obstruction that a stoppage had to be made for its removal. It has been stated, but the author thinks erroneously so, that the difficulty with regard to the snow, in these earlier cold-air machines, was due to the cooled compressed air not being sufficiently deprived of its moisture before admission to the expansion cylinder, or in other words that it was due to the absence of some form of interchanger. This, however, could not have been the case, for it is obvious that working in a temperate climate like that of Central Europe, the cooling water would be sufficiently low in temperature to cool the air considerably below the extent to which it is cooled in the tropics, even with an interchanger. Besides, this snow difficulty was entirely overcome by Giffard in 1873, by means of a separate exhaust valve with direct passages, and the author can state from his own experience that Giffard's machines can be worked continuously without the slightest trouble from accumulation of snow or ice.

In 1877 Messrs. Bell and Co., of Glasgow, who were then engaged in the importation of fresh meat from America by means of ice, consulted Sir W. Thomson, who nearly thirty years before had given his attention to the subject, as to the best kind of refrigerating machinery for use on board ship. Sir W.

Thomson, being aware that Messrs. Young and Co. had at their oil works a machine for cooling and condensing hydrocarbon gases by their compression and expansion, which was worked under the direction of Mr. J. J. Coleman, introduced Messrs. Bell to that gentleman, the result being that in 1877 a machine, since known as the Bell-Coleman dry-air refrigerator, was constructed. The principal novelty in this apparatus consisted in the precautions taken to prevent stoppage of the whole in case of accident. For this purpose no less than four compression, two expansion, and two steam cylinders were provided. The air was cooled during compression by injection, the water being subsequently separated by baffle plates, while the compressed air was still further cooled by means of an interchanger similar to that of Siemens and Windhausen. The Bell-Coleman refrigerator was successful in practice, but in the author's opinion, notwithstanding the use of the interchanger, the quantity of snow made was excessively great. It was not a very efficient apparatus, as owing to the construction of the slides of expansion cylinder, which were practically the same as those of an ordinary steam engine, a thin film of ice formed upon the slide faces, and this, by forcing the valve back, produced considerable leakage of air, which therefore passed through the cylinder without being cooled to the extent to which it should have been. The attentive consideration of the indicator cards published in Mr. Coleman's paper read before the Institution of Civil Engineers in 1882, shows that very serious leakages were taking place. At the same time, the introduction of the Bell-Coleman refrigerator was attended with a considerable amount of success, but the ratio of refrigerating power to chamber capacity was unnecessarily large as compared with more improved machines, and the cost of working greater than it should have been. Later, as experience was gained, the design was somewhat modified, the alterations tending chiefly to simplification and reduction in the number of working parts.

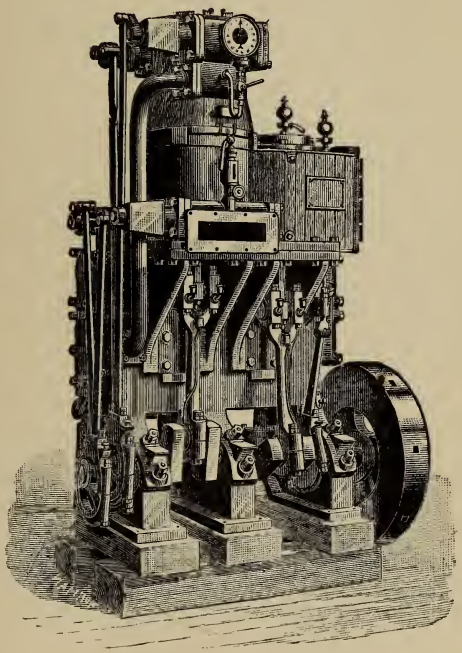
In a paper such as this, it would be impossible to describe in detail all the cold-air machines in use at the present time. Such a task is indeed unnecessary, as the principle of working is the same in all, the differences lying only in mechanical arrangements. It will suffice to state that the Haslam Foundry Company, Limited, of Derby, have largely manufactured an apparatus with an interchanger, which, if rather complicated, has done good work. Mr. Haslam followed Giffard and others, in having a separate valve for the exhaust from the expansion cylinder, and so obviated some of the difficulties experienced with the Windhausen and Bell-Coleman machines. Haslam's exhaust valve is,

however, an ordinary slide, and if the adjustments are not very carefully attended to, permits leakage at certain times, which materially interferes with efficiency. Messrs. J. and E. Hall, of Dartford, also manufacture a machine of exceedingly neat appearance, under Ellis' patent, in which the three cylinders, i. e. compression, expansion, and steam, are placed side by side at the end of a frame supported by the coolers. All the cylinders are worked by slide valves.

The author's machines for use on board ship, as manufactured by Messrs. Siebe, Gorman and Co., London, are shown in Figs. 2 to 6. The main objects kept in view in their design are simplicity, efficiency, economy of construction, and compactness. In no case is an interchanger employed, as the author believes such an apparatus is of no practical value, while it increases first cost and adds to the complication of the plant. It is not denied that by subjecting the compressed air to the additional cooling action of the cold air leaving the chamber, a lower terminal temperature should be attained than if water is the only cooling agent employed. But on the other hand if the cold air from the chamber is drawn directly into the compressor, together with such additional air from outside as is necessary to fill the cylinder at atmospheric pressure, a greater weight of air will pass through the machine per revolution than if an interchanger is used, the result being that the greater weight, and consequently greater volume dealt with, will in practice add more cooling power than what is gained by the lower terminal temperature of the lesser volume produced by the use of the interchanger. So far as dryness of the air is concerned there is no difference, as long as temperature and pressure remain the same, inasmuch as the air is always in a saturated condition for that temperature and pressure.

Figs. 2 and 3 show the largest sizes of machines, for delivering from 60,000 cubic feet of cold air per hour and upwards. The compressor is double acting, and the expansion cylinder single acting. They are placed close together tandem fashion, leaving room for examination and removal of the pistons, with one rod common to both cylinders. In this way the coldest part of the expansion cylinder is removed from the hottest part of the compressor, and the expansion exhaust port is kept short and direct. The air valves are circular slides, actuated by eccentrics. They are noiseless in action, and wear well without attention. The air, after being compressed in the cylinder, passes into the coolers, which are placed in the bed plate, and consist of a pair of welded steel vessels containing clusters of solid drawn Muntz metal tubes. Water is circulated through

FIG. 6.



To face p. 112.

Fig. 2.

SIDE ELEVATION

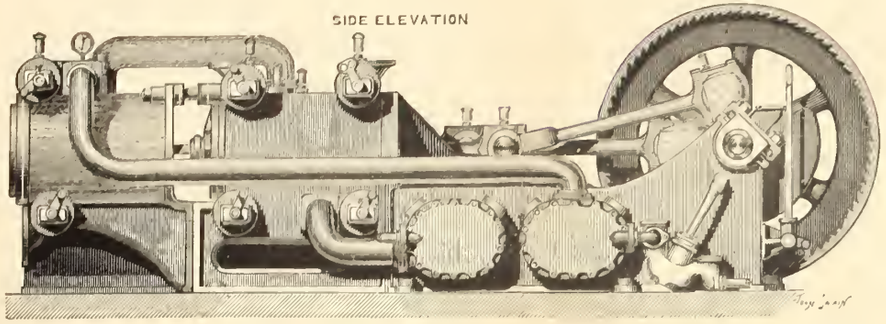


Fig. 4.

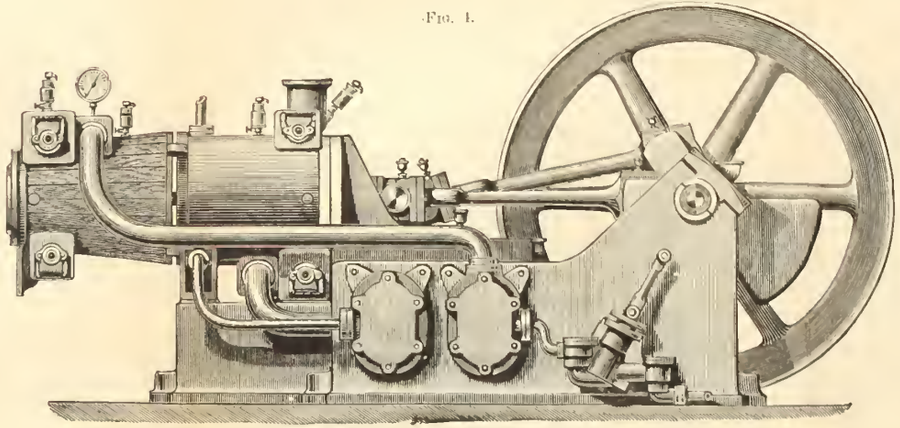


Fig. 6.

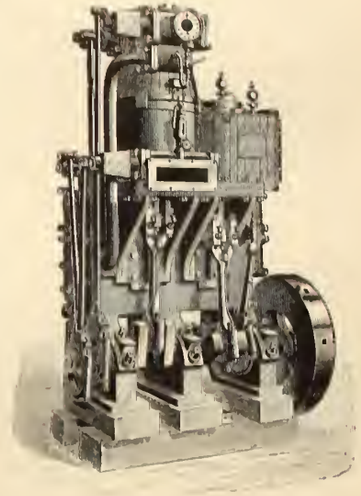


Fig. 3.

PLAN

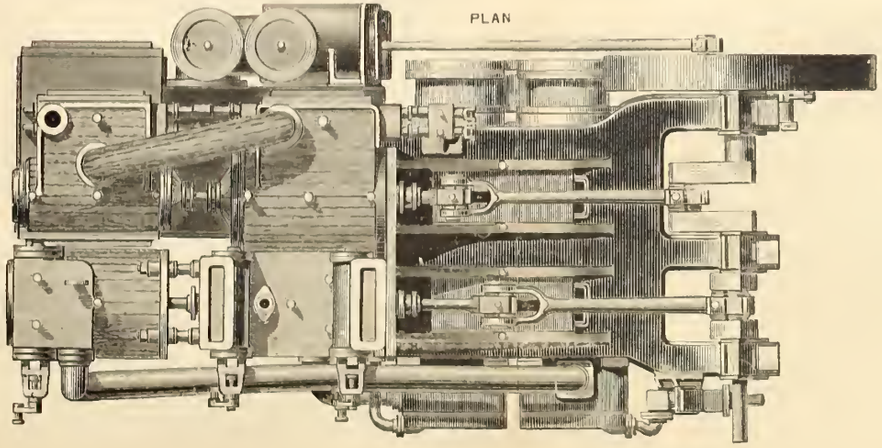
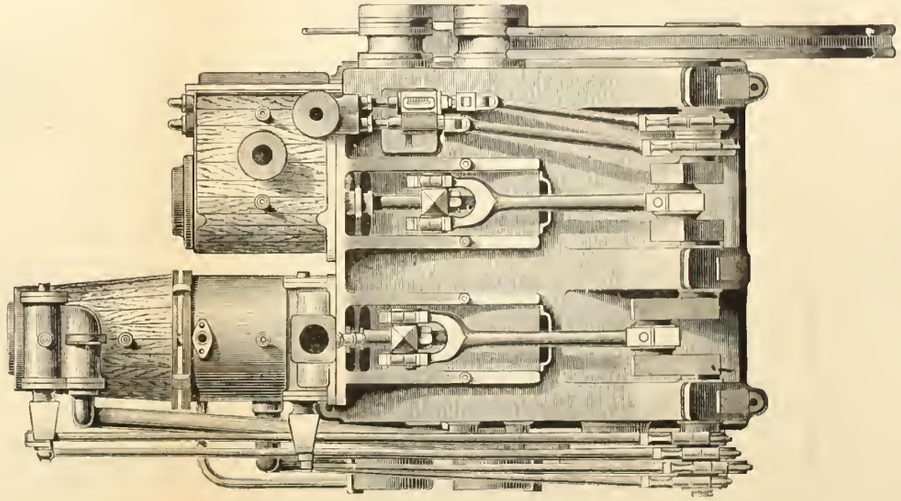


Fig. 5.



To face p. 112.

the inside of the tubes by the pump, the supply passing first through the tubes and then through the compressor jacket. The water condensed from the air in the cooling process is deposited in the coolers and blown off from time to time. From the coolers the compressed air passes to the expansion cylinder, where it performs work upon the piston, returning about 60 per cent. of the power expended in compression, and is then exhausted, cooled to from 60° to 100° below zero Fahr. or even lower, depending upon the initial temperature of the cooling water, and the degree of compression. The steam engine is of the compound tandem type, with the low-pressure cylinder in front. Below the high-pressure cylinder is the surface condenser, with the air pump at the side worked by a connecting rod from a crank pin on the flywheel. The same water used in the air coolers also serves for the surface condenser.

In some cases, more especially when two machines are employed for one installation, the surface condenser is made distinct from the cooling machine. An arrangement of this description is at the present time being carried out by Messrs. Siebe, Gorman and Co., on board the s.s. *Fifeshire*, for the New Zealand trade. There will be one surface condenser common to two machines, with its independent steam engine working the air circulating and feed pumps, the tube surface and pump capacity being sufficient for both machines when working at their full power.

For air deliveries of from 20,000 to 40,000 cubic feet per hour, a similar style is generally adopted, but the steam engine is usually of the high-pressure type, and a condenser is added, with the air pump worked from a prolongation of the steam piston rod.

Figs. 4 and 5 illustrate a still smaller horizontal machine, delivering from 4000 to 10,000 cubic feet of cold air per hour. In order to secure compactness and simplicity, both of which are frequently of greater importance in small than in large machines, the compression as well as the expansion cylinder is single acting. In other respects the design and construction are practically similar to those of the machine illustrated in Figs. 2 and 3, but the coolers are made of cast iron instead of welded steel.

For the smallest sizes, the vertical type as shown in Fig. 6 has been very largely adopted. The space occupied is much less than with the horizontal machines, while all the working parts are equally accessible. In this case both compression and expansion cylinders are single acting, and the coolers, instead of being separate, are cast in one with the frame. The vertical machines are generally constructed for bolting up

against a bulkhead, but by a slight alteration to the base of the frame they can be made so as to be supported entirely by the floor.

The power required to be expended in driving, varies according to the capacity of the machine. With the largest sizes 100 lb. weight of air per hour can be reduced from 60° above to 80° below zero Fahr., with cooling water at 60° Fahr., for an expenditure of 1·8 indicated horse-power. This is equivalent to the abstraction of 916 units per pound of coal with a consumption of 2 lb. of coal per indicated horse-power per hour. With the smallest sizes the same weight of air can be reduced from 60° above to 40° below zero, with cooling water at 60° Fahr., for an expenditure of 2·4 indicated horse-power, which is equivalent to an abstraction of 197 units per lb. of coal with a consumption of 5 lb. of coal per indicated horse-power per hour. The quantity of water for cooling the compressed air is of course dependent upon the efficiency of the cooling surfaces. On board ship, where the supply is practically unlimited, there is no great reason for economy, and in the machines described, the usual practice is to allow about 40 gallons per 100 lb. weight of cold air discharged. By modifying the design of the coolers a much less amount than this can be made to suffice.

As typical of the applications of refrigerating machines on board ship, a description of the installation for the s.s. *Fifeshire*, already referred to, may be interesting. This vessel is being specially built for the New Zealand dead meat trade, and will be capable of carrying about 30,000 carcases of mutton. The machinery consists of two horizontal dry-air refrigerators, with compound surface condensing engines for working with steam of 160 lbs. initial pressure, the general design being similar to that shown in Figs. 2 and 3, but with the steam condenser detached from the machine. The refrigerators are placed in the 'tween decks. The meat chambers, which are in the fore hold, are practically below water level, and are insulated with charcoal and wood of a total thickness of about 9 inches, the air being distributed by means of wood trunks with openings controlled by slides. It may be interesting to state here that in 1886 no less than about 70,000 tons of fresh beef and mutton were imported into the United Kingdom in refrigerated chambers, while the total annual carrying capacity of the vessels employed in the New Zealand trade at the present time amounts to 800,000 carcases. Cold-air machines have also been applied for supplying fresh cool air for the ventilation of holds in which live cattle is carried. The *You Yangs* was fitted with one of the author's machines for this purpose in 1884, the results being extremely

satisfactory. The last reports showed that the vessel was regularly carrying about 240 head of cattle without loss, their condition on landing being so good that they realised the highest market prices.

An example of a different class of installation is that recently made on board the s.s. *Prins Frederik*, belonging to the Netherlands Steam Ship Company, and trading to the Dutch Indies. The machine is of the vertical type, and delivers the air direct into a box containing copper ice moulds. From this it passes into the meat chamber, and then into the vegetable and salt-meat room, returning to the machine through a box containing a water cooler. In case of the vegetable room becoming too cold, arrangements are made whereby the air can be taken back to the machine direct from the freezing chamber. A great number of these installations have been fitted on board passenger steamers. In many cases they have effected a considerable monetary saving, besides improving the diet of the passengers, who are now supplied with fresh meat, game, poultry, vegetables, milk, &c., throughout the whole voyage.

A similar, but smaller, installation is that on board Mr. J. Gordon Bennett's steam yacht *Namouna*; but in this case, owing to want of space, there is only one chamber.

The same machines have also been very successfully applied for the preservation of fish on board steam trawlers and carriers, both at home and abroad. The most remarkable instance of this kind is in a fleet of vessels fishing off the coast of Brazil, and running into Para, almost under the equator. Here, where fish was hardly known as an article of diet, a regular trade has been established, and with the aid of refrigerated stores on shore, no difficulty has been found in providing a supply of fresh fish, even in the height of an equatorial summer.

The foregoing examples will serve not only to illustrate the method, but to a large degree the extent, of the application of refrigerating machinery on board ship, though doubtless many other additional openings will suggest themselves to the minds of the Members. Notably, the question of ventilation is one which might be successfully grappled with by the aid of refrigerators, but as yet nothing has been done in this direction, though it has frequently been referred to. In conclusion, the author would observe that although machines of his own design have been much more fully dealt with than those of others, it is simply because he has had the greatest experience with them, and not from any desire to give them special prominence.

DISCUSSION.

Mr. JOHN STURGEON said that some years ago he was interested in cold-air machinery, but the threats which were fulminated at that time by Messrs. Bell and Coleman against all persons who should "make, use, exercise, vend or apply" any kind of cold-air machine in which the principle of producing cold by the compression and re-expansion of air in performance of work was employed, intimidated the gentlemen with whom he was associated, and they and he very soon dropped the subject. Mr. Lightfoot had managed to compress a large amount of information into a very short paper. In all the cold-air machines illustrated the steam driver, the compression cylinder, and the expansion cylinder were all geared together, so that they must be driven at the same speed. The relative proportions between the different cylinders were fixed and unalterable, whereas the work to be done in cooling the air must necessarily vary according to the initial temperature of the air to be dealt with. He believed that the object was to reduce the temperature to one uniform degree, a little above the freezing point, namely 33° or thereabouts, whereas the temperature of the air drawn into the compression cylinder must vary very considerably, and the work to be done in the reduction of the temperature to the required degree must be much greater in torrid regions than elsewhere. Every cubic foot of air compressed in the compression cylinder must be reduced in volume by the time that it reached the expansion cylinder through reduction of temperature, leakage, &c., and therefore the expansion cylinder was invariably made smaller in capacity than the compression cylinder. If they began with a very high temperature the air must be compressed to a greater extent, the leakage would be more, the reduction of volume due to temperature would be more, and the volume reaching the expansion cylinder would consequently be less than when they dealt with a lower initial temperature; therefore either the air would be too great in volume for size of the expansion cylinder by the time that it reached it, and so not be expanded fully, and not have the full work taken out of it, or it would be too small in volume and not fill it. It had therefore occurred to him that it would be better to have the expansion cylinder working entirely independently of the other cylinder, and without assistance from the main driving power, though it might be employed to compress air into the same receiver. Then, whatever the grade of compression, the expansion cylinder would be free to adjust itself to a speed which would take most

work out of the air, and bring about the most economical result. In the compressed air power distribution scheme which he was now carrying out at Birmingham, it was the intention to apply the air power for refrigerating to a considerable extent, and there, of course, the refrigerating plant would be reduced to an expansion cylinder only, which could be employed on independent work. He had found that the air-driven engines, having no assistance from steam engines or other outside power, would produce cold very rapidly, and the difficulty was rather to deal with and keep down the cold they produced.

Mr. SCHÖNHEYDER said that he had been highly pleased with the paper. He thought that no one was more capable than Mr. Lightfoot of saying what was useful on the subject. Some years ago, when Giffard's machine was first brought over to England, everybody was in a fog as to what was required of refrigerating machinery for use on board ship. Giffard's machine was vertical, and it took up far too much height for use on board, and there were other difficulties in connection with it. Meat was being brought from America at that time, but the machines used would not compare with those of the present day. Mr. Giffard had himself told him (Mr. Schönheyder) of the difficulties which he had had with slide valves, from the ice clinging to them in the expansion cylinder. Mr. Giffard overcame that difficulty, as Mr. Lightfoot had pointed out, by using a mitre valve and making it rather sharp, so that it would actually cut the ice if it formed upon it. There was no mistake about a low temperature being produced by the Giffard machine. He remembered the mercury going down to 38° below zero, which was the freezing point of mercury, and consequently they could not observe any further fall of the temperature. He observed that the author used slide valves entirely in his machine. He should be glad to know whether any difficulty was found from the ice upon them, and if not, why not. A difficulty from that cause was found in the earlier machines. He should also like to know whether there was any special reason for using the welded steel coolers. Was there less leakage through them than through cast iron, or were they cheaper? When he made his examination of the Giffard machine he found that the economy of it was very poor. Had any progress been made in that respect? Of course for use on board ship the economy was not very important, because the machine was very small compared with the main engines, and did not use much fuel. In such circumstances the space occupied was perhaps more important than economy of fuel. The figures showed that the

amount of heat expended in the steam engine for driving the refrigerator was greater than the amount of heat abstracted in the cooling of the air, and the machine was therefore very extravagant compared with what other cooling machines did. It ought to be borne in mind that, strictly speaking, to cool a substance they ought not to require any power whatever, as they merely wanted to shift the heat from one place to another. What they sought to do was similar to the shifting of a railway truck from one siding to another, but they had not to lift the truck. They ought not, therefore, to require much power to do it, as they merely had to overcome a little friction. He could not help thinking that although the machines which had been described had a certain amount of simplicity, yet an air-cooling machine was to some extent a mistake, because the heat could be abstracted by other means, and with much less cost in fuel.

Mr. Robert Carr said that, having had some years' experience with machines of various sizes, beginning with a 10,000 cubic feet machine, and increasing to surface condensers of 60,000 feet capacity, he would recommend makers and users to adopt the most economically working machines. Those shown on the diagrams were apparently very good ones. He would recommend compound surface condensers for various reasons, namely, economy in fuel, better water for the boilers, and less cost for repairs. Machines could not be made too simple or too direct in their action. He had had some experience of machines in which there were levers and joints and other parts which caused a very great deal of trouble, and therefore he said the more direct the machine the better. Then, having a good machine, the next important thing was the chamber. If they had not a good chamber, well and perfectly insulated in every part, they would be throwing their cold air away to waste. To spend money in perfecting the chamber was a very wise thing to do. Another important consideration was the conveyance of air from the engine to the chamber. That was very much affected by the presence of elbows or bends in the pipes which conveyed the air. He would recommend a straight line from the engine to the chamber wherever it was possible. The abstraction of the heated air was another point which required very careful manipulation. If care was not taken, they might be drawing out some of the cold instead of the heated air. Where there was a large number of chambers, such as he had at the Royal Victoria Dock, it was very important that there should be regulators or slides for the admission of the air to the chambers, and for the return air, worked by some mechanical means from without. They had heard mention of "dry" air. In his experience of refrigerating engines there was a good deal of

snow in the air. The air in the chamber might be dry to some extent, but if the snow was not got out of the air before it reached the chambers, there would be snow in the chambers. If they could prevent the snow from accumulating, or find some means of dispersing it, either mechanically or chemically, it would save men having to be employed at some expense to clean out the snow, and the stoppage of the machines for that purpose. The present practice of ascertaining the temperature of a chamber was to send a man inside to look at the thermometer. It would be a very nice arrangement if the thermometers could be so constructed as to register on the outside of the chamber the temperature within. The subject of refrigerating meat was one of national importance, because it was connected with one of the sources of the food supply of this country, and it was desirable that machines employed for the purpose of refrigerating should be worked at the least possible cost, and the benefit would ultimately come to the consumer in the form of cheaper meat.

Sir James Ramsden, upon being invited by the President to join in the discussion, said that he was afraid that he was not in a position to offer any observations which would be useful to the Society. He took great interest in the question, being connected with steamships in which the Bell-Coleman machine had been applied from time to time, with great success. From what Mr. Lightfoot had told them, there was no doubt that certain economies had been introduced which every one would appreciate.

Mr. Arthur Rigg said that from what they had heard that evening it was evident that a great revolution had taken place during the last few years in relation to our meat supply; which was, he thought, another of the benefits which the country owed to engineers, who had done more than any other class to advance the comforts of the people.

The machine which had been described seemed an exceedingly good example of scientific engineering, although its parts might have been collected from all the ends of the earth and designed to fit together. The author had used a description of Corliss valves which were very successful, and which he (Mr. Rigg) had seen in as good order after many years' working as they were on the day they were put in. One speaker had made an objection which, though possibly correct in strict theory, seemed of little practical account, because, when machinery is designed upon principles correct in the main, it is generally found to withstand a far greater amount of mismanagement without going beyond the margin of safety, than can be the case when designed upon wrong principles. This machinery had a very

complicated look as it was represented in the diagrams, but perhaps in reality it would not look so complicated. Mr. Lightfoot had shown very great ingenuity in the design, and he thought that, after a time, when the machines had, possibly, got more into use, the details would become more simplified.

Mr. PERRY F. NURSEY said that the reference made by Mr. Carr to the importance of proper construction of the freezing chambers led him to make a suggestion. If he understood the author correctly, he constructed the walls of his chambers hollow and filled in the spaces with charcoal—powdered charcoal, he presumed.

Mr. LIGHTFOOT: Flake charcoal.

Mr. NURSEY would ask Mr. Lightfoot whether he had ever tried any other non-conducting substances. About twelve years ago he (Mr. Nursey) went over the Hasard Collieries at Micheroux, Belgium. They were very extensive, and connected with them was a large living-establishment for the workmen, the Hotel Louise. Attached to the hotel was a hospital which was constructed with double walls of timber, the spaces being filled in with fine sawdust. This material was found to be most effective in keeping out the cold in winter and in keeping down the heat in summer, although the hospital was in a rather exposed situation. Possibly sawdust might prove a much more economical material for filling the walls of the freezing chambers than charcoal, and be equally effective.

Mr. J. W. WILSON, jun., thought that all those present must have felt that the paper put before them the result of the judicious combination of theory and practice. He would suggest that they had not heard at present any details as to the relative cost of such of Mr. Lightfoot's machines as had been referred to. It would be interesting, he thought, to have information on that point. Mr. Lightfoot's paper was professedly one on refrigerating machines as employed on board ship. It was obvious that had the author been asked to give a paper on refrigerating machinery generally, he would have had still more to say upon the subject and that many further points would have arisen for consideration. Some of these had been already touched upon by the speakers that evening, but in discussing the matter they should not lose sight of the fact that they were professedly asked to consider specially refrigerating machinery on board ship.

Mr. G. A. GOODWIN, alluding to Mr. Nursey's remarks, said that sawdust insulation was tried at the London and St. Katharine's Docks, the first installation of which he had charge, but it was discarded. Mr. Lightfoot had referred to drawing the air from the chambers back to the machines.

That was done at the docks, at his (Mr. Goodwin's) suggestion, when the installation was first started, and arrangements were made for drawing fresh air to mix with it; but the air was found to become tainted through continually circulating round the meat and through the oil and glycerine of the machine, and he believed that for that reason the system was discontinued. He should like to ask Mr. Lightfoot whether he did not find that the ports in the expansion cylinders got choked up with snow. They appeared from the drawing to be long and rather narrow. How long would the machines work continuously? and had he any fixed proportion between the length of the stroke and the diameter of the air-expansion cylinder? With respect to the working of the Giffard's machines, two were fitted up on board the *Teviotdale*, which vessel was chartered by the Australasian Fresh Meat Company, while he was acting as consulting engineer to the company, and they worked very well indeed. Mr. Sturgeon had said that he was going to use the compressed air, now being laid on for public supply in Birmingham, for refrigerating purposes. He should like to ask him what work the air-expansion cylinders would have to do, as, of course, unless energy was taken out of the air, no reduction of temperature was possible, and he suggested that this should be done by compressing other air and so reducing the demand upon the public supply. The lowest temperature which he had ever seen obtained by a refrigerator was in a large machine at the London and St. Katharine's Docks, made by Messrs. Hall. Special thermometers were made in the Kew Observatory, and they registered 110 degrees below zero. He put a pot of glycerine in the snow box, and it was frozen perfectly solid. As to Mr. Carr's remarks about ascertaining the temperature in the chambers, he thought that it might be done by inserting two long rods of different materials through the chambers, fixed at one end and projecting outside the chamber at the other; and as they would expand and contract differently, the free ends could be made to actuate an index. They could thus show what the average temperature was in the chamber, but of course they could not localise the temperature. As to doing away with the snow formed in the act of expanding the air, Messrs. Hall tried to accomplish that some years ago by means of an Archimedean screw in the snow box, the screw surface of which formed the snow baffles. The snow was thus delivered at one end and made to fall on the conduct pipe through which the compressed air was passing to the expansion cylinder, which cooled the air, and converted the snow into water.

Mr. W. A. Gorman said that he had taken up the manu-

facture of the machine described in the paper on account of its great simplicity. There was nothing complicated in the machine, all parts were accessible, and he had found it worked perfectly for a considerable length of time without repairs or adjustment being necessary. In fact, only the last week he had a letter from the managing director of a steamship company, stating that one of the machines had been working continuously from the first week in January, and was still going as perfectly as when it began, although their engineers had no previous experience in the working of refrigerating machinery. He thought that statement was very much in its favour. For passenger steamers, the small vertical machine was well adapted. It was very compact, and could be bolted up against a bulkhead. An ordinary engine-driver could attend to the machine and cold storage room. For passenger steamers in the tropics the machines added considerably to the comfort of all on board, as fresh meat could be carried, also milk, fruit, fresh butter and vegetables, and a daily supply of ice could be made from filtered water.

Mr. STURGEON, answering Mr. Goodwin's question as to what work the expansion cylinders of the machines at Birmingham might be set to perform, said that in most places there might be some motive power required, and in such case the engine could be applied to do the work; but in a case in which the engine had no specific work to perform, the expansion cylinder could be run simply against the brake. There would be no disadvantage in that: in fact, the user would be saved the cost of the other portions of a cold-air machine—the steam boiler, the steam cylinder, the compression cylinder, and all the other moving parts. The expansion cylinder would be no more than it was now; and although the work would be, as it were, wasted in being simply performed upon the brake, yet a *quid pro quo* would be obtained in the cold which was produced. In the machines illustrated, of course, the whole work done by the steam cylinder was expended in the production of cold. The plan suggested by Mr. Goodwin, viz., to employ the cylinders to compress air back into the mains, was a very good one, and might be employed where the engines were large enough to make it worth while to incur the expense of compression cylinder and pipe connections.

Mr. LIGHTFOOT, in reply to the discussion, said with regard to Mr. Sturgeon's remarks that it was not possible to enter into such a degree of refinement with the machines as Mr. Sturgeon indicated. It was, of course, quite true that in the tropics the cooling work was greater than in temperate climates, but that was got over by running the machine for a longer period. With

regard to the fact that, owing to the variation of the temperature of the air, a larger quantity would enter the compression cylinder, and consequently pass through the machine, in a given time in temperate climates than in the tropics, the only effect of that was that they would have a slightly higher terminal pressure after expansion in the one case than in the other. In practice, however, the air was drawn back from the cold chamber into the machine, so that the temperature was pretty nearly constant. In a voyage from New Zealand to this country, the temperature in the chamber would not vary more than, perhaps, 10°, so that really, although they were passing through very great differences in external temperature, the difference between the temperature of the air which entered the compression cylinder in the tropics and that which entered in a temperate region was not very great.

Mr. Schönheyder had asked very pertinently how it was that he did not experience difficulty with regard to the ice, as in the former cases he had mentioned. There were two reasons. In the first place the slides originally used, to which he (the author) had drawn attention, were similar to those used in ordinary steam engines. One slide controlled both the admission to the cylinder and the exhaust from it. In that case it was found that a thin film of ice formed upon the face, and this breaking off, produced a leakage from the store of compressed air in the coolers, air passing right through the expansion cylinder to the exhaust. In his machines, by having a separate inlet and a separate outlet, they did away with that difficulty altogether. The inlet valve was never cold, and there was no chance of ice being produced on it. It could only be formed on the exhaust. The other reason was that at each end of the exhaust valve there were turned portions which exactly fitted the recesses, and so prevented the valve from leaving the face, and it was found that after six months' work the tool marks were not even worn out of the valves. There was no apparent wear of the valves: they seemed as if they almost floated in their seats. He had not intended to lay stress upon the fact of welded steel being used for the coolers. The only reason for using that particular construction was that it was rather nice. He had made many machines with cast-iron vessels, though not of the size mentioned in the paper. The remark of Mr. Schönheyder as to cooling not requiring the expenditure of power was, of course, quite true, so long as they had something to which they could transfer the heat. The difficulty, in practice, was that they were dealing with temperatures below the normal, so that the thermal conditions of the material had to be modified, and, to accomplish this, power must be expended

in order to raise the temperature above the normal. As to the thermometers, there were several of such instruments in use for indicating outside the chamber the temperature within. Towards the close of last year he went over several large stores in America, and he found that such thermometers were regularly used there. In the manager's office there were dials upon which the temperature of the various chambers was indicated. These instruments were, however, rather expensive, costing about 12*l.* each or more. They were made by the Telemeter Company of New York. There was also a firm in Glasgow which supplied a thermometer for the same purpose, but of which the construction was different.

In answer to Mr. Nursey, he would say that he had tried the use of sawdust for insulation, but he had been compelled to take it out, owing to the ravages of the rats. He had also used silicate cotton in very exposed positions. The chamber in Mr. J. Gordon Bennett's yacht was insulated with it. The three substances which he had used were charcoal, silicate cotton, and sawdust. Charcoal was a cheaper material than silicate cotton, and answered perfectly. As to Mr. Goodwin's question whether the ports ever got furred up, he had never had such difficulty, and his own belief was that the machines could be worked for ever without any such furring taking place. He had no fixed proportion of stroke to diameter, though of course they generally got as long a stroke as possible. But very often the position in which the machines had to be erected defined the length of stroke. As to the air drawn from the chamber becoming tainted, he did not think that such a thing happened at all. He had never known it to occur in his experience. Very often they made arrangements for drawing a little fresh air from the outside, but the object of this was to prevent the tendency to form a vacuum within the chamber. They simply had a small hole in the suction pipe. This allowed a little air from the outside to enter at every stroke, and freshened up the whole of the air at the same time.

At the request of the President, Mr. Lightfoot afterwards supplied the following approximate costs of the machines illustrated, including steam engines:—

	£
To deliver 4,000 cubic feet of cold dry air per hour	350
„ 10,000 „ „ „	575
„ 40,000 „ „ „	1450
„ 80,000 „ „ „	2250

June 6th, 1887.

HENRY ROBINSON, PRESIDENT, IN THE CHAIR.

RENEWAL OF ROOF OVER DEPARTURE PLATFORM AT KING'S CROSS TERMINUS, G. N. R.

By R. M. BANCROFT, Past President of the Civil and Mechanical Engineers Society.

THE Great Northern Railway passenger station at King's Cross was finished and opened to the public in 1852, and its then laminated timber roof, to which the author will first call attention, was built during the two previous years; a transverse section showing its two arcades is given on Plate 1.

The ribs consisted, as will be seen from Plate 2, of seventeen planks, as follows:—

	Width. inches.	Depth. inches.
8 planks	8½ ..	12
7 ditto	10½ ..	10
2 ditto (with beads at edges) ..	6½ ..	2
17 planks, giving a depth of		24 inches at the crown,

which increases downwards to 2 feet 3 inches at the top of spandril casting; the top laminations then merge into the solid timber, while the lower laminations are continued down to and rest on the corbel shoe. The ribs, or principals, were built upon a platform of sleepers of triangular section, such as were at that time used for the permanent way; these were laid out radially to suit the curve of the rib, upon the ground at the south end of the station, and held together by iron tie bolts. Wooden blocks were secured to the sleepers at a radius corresponding to the intrados of the arch, and the first layer of planks bent to this curve.

On the first layer a second one was placed and fastened thereto by 3-inch wood screws 8 inches apart, and the two were temporarily held together by iron clamps to the blocks, and similarly until the whole thickness of the rib was completed, care being taken that all the planks broke joint with one

another. A band of wrought iron 4 inches by ½ inch, fished at joints, was finally placed round the extrados, and both wood and iron bolted together by ¾-inch bolts about 2 feet apart; as will be clearly seen from drawing No. 2. The timber ribs were hoisted into place by three derricks, one placed against each wall and one in the centre. The total weight of a timber rib was 3 tons 12 cwt.

It will be seen from the drawing of this roof that no provision was made for ventilation, or escape of the sulphurous fumes and steam from the locomotives; this, no doubt, had an injurious effect on the ribs and partly hastened their decay. When erecting the old roof in 1850 at the south end of the station, provision for the thrust on the east side was overlooked, and the east wall next York Road was pushed outwards by the ribs. After getting them back into position, the heavy timber trussing shown on drawing No. 1 was erected over the cab rank, the principals being in a line with each rib, to take this outward thrust, but the first few ribs were never quite reinstated to their proper curve, and on completion presented the appearance of being flattened at the crown.

The system of laminated timber roofing appears to have been introduced by Colonel Emy, a French military engineer, who published a series of designs showing this method, of which three examples are given on Plate 1.

In 1868, or about eighteen years after its erection, it was considered necessary to take down the old wooden roof over the eastern arcade and erect in its place an iron one, similar in design to the iron roof over the old Great Northern passenger station, Bradford, now used as a goods station (see Plate 3), which roof the author measured up at that time. This renewal was carried out by the late Mr. John Jay, contractor, the ironwork being supplied by Messrs. Westwood, Baillie, and Co. The greater part of the timber in the roof taken down was re-used for railway purposes. After the renewal of the roof over the eastern side, the wooden roof of the western arcade was occasionally inspected and the ridge levelled, so as to ascertain if any settlement might be taking place.

In 1886 it was decided to renew the roof of this arcade by an iron one similar to that erected over the eastern side. Messrs. A. Handyside and Co., of Derby, obtained the contract at 18,850*l*.

In erecting the work a movable staging (see Plates 4 and 5) has been employed, so as not to interfere with the departure traffic, and 19 feet headway is left over the lines of rails, to permit locomotives, carriages, &c., to pass underneath.

When the staging was first made, in 1868, for the renewal of the eastern arcade roof, the railway company contracted with

Messrs. Cliff and Son, Bradford, to supply the four wrought-iron plate girders and cross tie plates fixed in place on top of trestles for 745*l.*, and the fifty-two cast-iron wheels with wrought-iron axles, forty single and thirty-two double bed-blocks, 104 chilled bearing-blocks, and twenty strut shoes for 215*l.* The company found all the timber and let the contract for labour only to Mr. Plowman, of Boston, at 8½*d.* per cubic foot, the staging to be erected at the south end of the station in working order ready for the erection of new roof. The timber was measured up and found to contain 12,315 cubic feet.

The above enumerated wrought- and cast-iron work, and most of the timber used in the staging at the renewal of the eastern arcade roof in 1868, are now being re-used in the present staging, having been numbered, lettered, and stored away since that time, any faulty timbers being replaced by new. The whole of the old flooring had been used for other purposes, necessitating all new flooring to be supplied in this contract. This supply and the reframing and erecting of the travelling stage, as also its removal on completion of the work, are included in the contract sum given on page 2.

There are two trestles, each provided with thirteen pairs of 3 feet 6 inches diameter double-flanged cast-iron wheels, with 4-inch wrought-iron axles, as shown on drawing No. 5, one trestle for working along the departure platform, on rails secured to the longitudinal balks of timber, which are moved as the work advances; and the other trestle for working on the rail level. The main vertical timbers are 12 inches by 12 inches, the struts 12 inches by 12 inches and 12 inches by 9 inches, and the longitudinal bearers, close underneath the girders, are 12 inches by 12 inches, the cross bracing and side longitudinals are 12 inches by 6 inches. The departure platform, which is of Yorkshire landings, on cross-sleeper brick walls, has to be strengthened by strutting underneath as the staging advances, to enable it to carry the weight of same.

After erecting the trestles, the four plate girders, each weighing over 13 tons, were hoisted into place by a 14 inch by 14 inch timber derrick with pulley blocks, in the usual way, a 20-ton crab being used. The girders being securely bolted to the 12 inch by 12 inch timber bearers at top of trestles, the upper portion of the staging was erected thereon. There are three floors, and on the topmost floor is placed a steam crane with revolving jib (see Plate 5), for hoisting and depositing materials on the floors as required.

The vertical timbers of staging are of 10 inch by 10 inch pitch pine, and in one length. The cross bracing is of yellow deal and the flooring of 2½-inch battens, and in the staging

complete for work there are about 13,000 cubic feet of timber; the estimated weight with all working appliances thereon is about 300 tons. To move this staging, when one bay or 20 feet of roof is complete, a spare set of movable rails is laid down in front of those on the platform, and the staging is then hauled along by four workmen on the platform, and eight men on the rail level, using double-purchase crabs and rope, and twenty-five minutes are occupied by each removal. The length of rails left behind is then taken up and placed by the side of the trestles, to be again used at the next removal. When the contract is completed, it is proposed to use the four plate girders for bridge purposes, they having been designed so that a portion of each end can be detached, leaving a girder suitable for a railway bridge of 64 feet span. The timber in the scaffolding will be used for various other work.

Before commencing to remove the old ribs, the centre wall of station has to be strutted, so as to provide for the thrust from the opposite ribs over the eastern arcade. This is done by placing vertical timbers 12 inches by 6 inches at each side of and close to the old rib, and against the walls, and strutting them to longitudinal timbers 12 inches by 12 inches placed on the first and second floors of the staging against the vertical timbers, as shown on Plate 5. The strutting being wedged securely, the work of taking down the rib may be safely commenced. The work began at the south end of the station, where the staging was erected, and the old roof covering of glass, bevelled iron glazing bars, timber, slates, &c., was first stripped off and lowered by steam crane into trucks on the rails. The 4 inch by $\frac{1}{2}$ inch wrought-iron band on top of laminated rib was then unbolted and taken off. A length of rib was next cut out at centre, the rib resting on the temporary trestles fixed on the top floor of staging, and being strutted for further security; other portions were then cut off at convenient lengths, let down into trucks and taken out of the station as directed. The top spandril casting was removed from the old rib and left on the second floor of staging, to be shortened and rounded at its upper end to fit the new wrought-iron rib. The cast-iron spandril ring, and lower portion of spandril filling, were left in place, being securely bolted to the old cast-iron stanchions built into the walls, and holes for $\frac{3}{4}$-inch bolts are drilled through them, where required, for bolting to the flanges of the lower end of the new wrought-iron rib. Each successive rib has been similarly treated.

The normal span of roof between the piers is 105 feet 3 inches, but a careful measurement by a steel tape at several ribs showed a variation from 105 feet 3 inches to 105 feet

$1\frac{5}{8}$ inches. The height from rail level to top of rib is 73 feet 9 inches, and the apex of ventilator is 5 feet 10 inches above this, making a total extreme height of 79 feet 7 inches. The normal distance apart of the principals is 20 feet centre to centre, and a measurement of the forty bays showed a total loss of 4 inches in the whole length, to compensate for which the purlins in two bays will be shortened.

The inner radius of the rib is 51 feet 3 inches, and the outer 54 feet; making the depth at crown 2 feet, and at top of spandril 2 feet 3 inches. In the construction at the contractor's roof and girder yard in Derby, the ribs are set out to these curves on a platform, and the joints of the ironwork so arranged that the rib may be divided into seven parts, for convenience of transit by railway. The rib is built up in plate-girder fashion, with $10\frac{1}{2}$ inch by $\frac{1}{4}$ inch top and bottom flange plates, and 4 inch by 4 inch by $\frac{5}{16}$ L-irons throughout (see Plates 6, 7, and 8). The joints in the L-irons to top and bottom flanges have covers 2 feet long, of the same section, and are arranged to break joint with each other, and also with those in the flange plates; the joints in the latter are 2 feet 8 inches long, and of the same width and thickness as the flanges. All ends of flanges and web plates are made to butt truly against each other. The web from crown to top of spandril is $\frac{1}{4}$ inch thick, and below this point, where the rib is divided at spandril, and down to where it rests on the corbel stone, it is $\frac{3}{8}$ inch thick; the pitch of rivets throughout is 4 inches.

The lower part of the rib is divided at the haunches, to enclose the cast-iron spandril ring and filling, which formed part of the old roof, and are bolted to stanchions built into the walls when the station was erected (see Plate 2). To remove these stanchions would have necessitated the cutting away of a considerable quantity of brickwork, and have added materially to the cost. At the springing of the rib, where it rests on the corbel, the web is covered by cast-iron moulded panels bolted on each side (see Plate 7). To ensure accuracy in the construction of the ribs, wooden templates were first made of the old spandril rings and filling, and the haunches of the new iron ribs constructed to fit them, and in most cases the ribs as sent out of the contractor's yard have exactly fitted.

Comparing the King's Cross roof with that at Bradford, it will be seen on Plate 3 that in the older semicircular roof the principal or main rib is of one section from crown to the foot, where it rests on the bed plate built into wall.

This construction is, in the author's opinion, better than dividing the rib at spandril, as in the King's Cross roof, as the strain in the latter has partly to be taken by the spandril ring,

while in the Bradford roof the whole strain travels to the foot of the rib, and the heavy spandril fillings and moulded panels are avoided.

Spanning between the ribs there are six purlins on each side, of which, counting from the top of spandril, Nos. 1 and 6 are lattice, and Nos. 2 to 5 inclusive, trussed purlins. The lattice purlin No. 1 at the bottom of the glazing (see Plate 6) is constructed with top and bottom flanges of T-iron 5 inches by 4 inches by $\frac{1}{2}$ inch, lattice bars $2\frac{1}{2}$ inches by $\frac{1}{4}$ inch, and T-iron verticals $5\frac{1}{2}$ inches by 2 inches by $\frac{3}{8}$ inch, dividing the whole length of the purlin into three equal panels (see details in Plate 8). The purlins are bent at their upper ends, so that their top surfaces may be level with the flange of the main rib, to which they are riveted as shown. An angle iron 6 inches deep by 3 inches by $\frac{3}{8}$ inch is riveted to the top flange of the purlin, and runs the whole length of the roof; to it are riveted the 2 inch by $\frac{1}{4}$ inch horseshoe ventilators, 16 inches apart, and to the tops of these ventilators is riveted an L-iron $2\frac{1}{2}$ inches by $2\frac{1}{2}$ inches by $\frac{3}{8}$ inch for carrying the ends of the T-iron glazing bars (see Plate 7). The lattice purlins No. 6 are constructed exactly of same scantling as No. 1, but riveted on to top of main rib, end to end, so as to be continuous and elevated as shown on Plates 6 and 9, thus giving a pitch of about 20° to the top length of glazing just above the upper gangway. On the roof over the eastern arcade this is not so, and the glazing there is at an angle of 8°, at which, it is found, the rain does not wash it of smuts, dirt, &c., as in the steeper pitches. There being no wall at the north end, the two last ribs are placed 12 feet 4 inches apart, and braced together by the purlins which are at this part of the roof made stronger than elsewhere, the flanges being here of T-iron 5 inches by 4 inches by $\frac{1}{2}$ inch with cross bracing of 5 inches by 2 inches by $\frac{3}{8}$ inch T-iron (see Plate 9). The I-iron intermediate rafter between the end ribs is also made continuous from wall to wall. The trussed purlins Nos. 2 to 5, as shown on Plates 6 and 8, are made of 5 inch by 4 inch by $\frac{1}{2}$ inch T-iron, trussed with $1\frac{1}{8}$ inch round bars forked at ends to clip corner plates which are riveted to main rib and T-iron. On the T-iron of the purlin a longitudinal double angle or Z-iron 4 inches by 2 inches by $\frac{3}{8}$ inches is riveted with $\frac{3}{4}$-inch rivets 6 inches pitch.

In each bay of 20 feet there are four (two on each side) intermediate I-iron rafters 8 inches by 5 inches by 5 inches by $\frac{1}{2}$ inch; their upper ends are riveted to lugs secured to No. 1 lattice purlin, and their lower ends bolted to cast-iron shoes built into the wall on stone templates (see Plate 7). It was

not deemed necessary to have wind bracing for this roof, the twelve purlins being considered sufficient to securely tie the principals together, and none having been used in the Bradford roof (see Plate 3). For the glazing, wrought T-iron bars 3 inches by $1\frac{3}{4}$ inches by $\frac{3}{8}$ inch are used, packed with wedge-shaped pieces of malleable iron to suit the angle of the Z-iron on which they rest and are riveted.

It is found in the span over the eastern arcade that the workmen lose much time in moving cat ladders during repairs, cleaning the glass, &c., and to obviate this on the western arcade two gangways are provided on each side, the lower one at the horseshoe ventilators, and the upper one at No. 4 trussed purlin. The timber runs are supported on $3\frac{1}{2}$ inch by 3 inch by $\frac{1}{2}$ inch L-iron brackets 6 feet 8 inches apart (three to each bay) fixed horizontally, those over the ribs are strutted up from top flanges with L-iron 3 inches by 3 inches by $\frac{1}{2}$ inch, the intermediate brackets of the lower gangway strutted from the I-iron rafters, and those of the upper from special I-iron glazing bars, $3\frac{1}{2}$ inches by $2\frac{1}{2}$ inches by $\frac{3}{8}$ inch, as shown on drawings Nos. 6 and 7. The timber runs are formed of two 9 inch by $2\frac{1}{2}$ inch battens, secured to the L-iron brackets with $\frac{1}{2}$-inch coach screws. Cast-iron standards of $\frac{3}{4}$-inch metal, with $1\frac{1}{2}$-inch gas-pipe hand-rails, are fixed for the safety of the workmen. A ladder is also provided at the south end by the clock tower, similar to the one over the eastern arcade. The sides of the ladder, which is fixed about 1 foot above roof covering, are 5 inches by $2\frac{1}{2}$ inches by $\frac{1}{2}$ inch T-irons, and the rounds of $\frac{3}{4}$-inch round iron, in pairs, fixed parallel and horizontal. It is supported on T-iron bearers 4 inches by 3 inches by $\frac{3}{8}$ inch, one end of which is built into the end wall of station, the other curved down and fixed to the third sash bar from end by the table of the T-iron bearer, being riveted to the web of the glazing bar. A hand-rail of $1\frac{1}{2}$-inch gas tubing to give handhold for workmen using it, as for the gangways, is fixed near the wall and supported on small wrought-iron brackets built into same.

Ventilation is provided at the ridge by an open louvre 12 feet wide, the apex of which is 5 feet 10 inches above the crown of the rib; the glass covering overlapping sufficiently to keep out drifting rain and snow.

The 4 inch by 3 inch by $\frac{1}{2}$ inch curved T-iron bearers and brackets are riveted back to back, and to the 6 inch by 3 inch L-irons on top of lattice purlins No. 6. Longitudinal 4 inch by 2 inch by $\frac{3}{8}$ inch L-irons are riveted to the overhanging ends of the curved brackets at bottom of the louvre, and to the bearers near the apex, to carry the sash bars.

On the louvre, Helliwell's patent glazing without putty is adopted, and special rolled iron glazing bars 8 feet 8 inches long, with double channels for carrying off water are used (see Plate 9). To each bar there are three zinc clips about 4 inches long, each of which is riveted to web of glazing bar with a copper rivet. The glass being placed on the bars, a zinc capping, which extends the whole length of the bar, is drawn over the web and under the clips, to hold the glass firmly in its place, no external fastenings being required. A wrought-iron stop 10 inches long by $1\frac{3}{4}$ inch by $\frac{1}{8}$ inch is attached to the L-iron, and clips the glass in the centre at the foot of the square to prevent it slipping.

Additional ventilation is also provided at the apex, where an opening is left covered by sheet iron capping of No. 12 B. W. G., stiffened at edges by 2 inches by 2 inches by $\frac{1}{4}$ inch L-irons and supported by $1\frac{1}{4}$ inch by $\frac{1}{4}$ inch vertical bars about 6 feet 8 inches apart, which are riveted to the 4 inch by 2 inch by $\frac{3}{8}$ inch longitudinal L-irons, resting upon the T-iron curved bearers. To ventilate under the gutter boards, once in each bay five $1\frac{1}{2}$-inch holes are provided in the V-jointed boarding, and covered at back with zinc.

After fixing the ironwork of one bay complete, the work of covering is commenced. On the upper flange of the rib two 6 inch by 3 inch, and on the intermediate rafters one 9 inch by 3 inch fir packings, wrought on outsides and stop chamfered, are fixed with $\frac{1}{2}$-inch coach screws, 12 inches apart. On these packings the $1\frac{1}{2}$-inch, wrought one side, grooved, tongued, and V-jointed batten boarding for slates is securely nailed; this extends the whole length of the roof to the height of the first purlin on each side. At the bottom of the boarding is an inside wrought one-side fascia and moulding. At the south end of the roof, under the ladder, $1\frac{1}{2}$-inch boarding, as described above, is substituted for glazing, for a width of 2 feet 8 inches with wood rolls to fit on to the webs of the glazing bars, all covered with 7 lb. lead and having 5 lb. lead flashing against wall. The whole of the slating of the old wooden roof will be re-used in the present work.

The whole of the glass used is Hartley's $\frac{1}{4}$-inch thick rough fluted. The glass below the louvre and down to top of slating is bedded on putty, and the top side of glass for a width of $\frac{1}{2}$ inch is painted, so as to give a better hold to the putty. There are about 7000 square yards of putty glazing, and 1540 square yards of Helliwell's patent puttyless glazing in this arcade.

The old lead gutters, flashing, stepped flashing, aprons, &c., are all removed and replaced by 7 lb. lead, turned up not less

than 6 inches at any point; new 1½-inch gutter boards with bearers, &c., being used. All rolls, drips, cesspools, &c., are renewed, the cesspools having 5-inch swan-neck connections of 7 lb. lead to the existing 6 inch down-pipes, protected by 7 lb. lead domical gratings. On each side the gutters are provided with snow lattices of 1½ inch by 2½ inch laths on 6 inch by 3 inch bearers, all creosoted, the top being about 8 inches above gutter level. These lattices are provided, so that snow cannot block up the gutters, but as it melts will drain through the lattices, and have a free gutter on which to flow away.

The north end of the arcade will be filled in with glazing above the level of the ceiling over the foot-bridge which connects the departure and arrival platforms. This glazing (partly shown on Plate 6) corresponds with that of the eastern arcade. A trussed wooden framing, consisting of horizontal beams, vertical timbers and struts, will be fixed across the whole width between the walls, and at the end fitted to main rib; a weathered and throated sill being provided for top of trussing, and the inside and outside covered with 1-inch wrought boarding, grooved, tongued, and V-jointed inside, and beaded outside. On this trussing moulded vertical timbers, with channel iron stiffeners and curved framing to fit inside the main rib, are to be fixed, the glazing bars being of wrought iron halved and mitred together. A moulded fascia with capping is provided to the front of the end main rib.

Tests of Wrought Iron.

The whole of the iron used is of English manufacture, and the contractors have had to supply wrought iron to bear the following tests:—

	Breaking Strain.	Contraction of Area.
	tons.	per cent.
Plates, with grain	21	10
Ditto, across grain	18	5
L and T bars	22	15
Round and square bars, and flat bars under 5 inches	24	20

Weight of Ironwork in One Bay of 20 Feet.

(The Average of Six Bays.)

Wrought.

		tons.	cwts.	qrs.	lbs.
1	Principal	6	17	3	14
4	Lattice purlins	1	17	1	25
8	Trussed ditto	2	0	0	18
4	Intermediate rafters	1	0	0	3
120	T-iron glazing bars	3	2	3	11
30	Helliwell's patent ditto	0	9	1	4
	Gangway brackets	0	4	2	14
	Horseshoe ventilator	0	0	3	4
	Ventilator at ridge	0	17	3	27
	Gas-pipe handrail	0	1	3	0
	Bolts and nuts	0	0	2	17

Cast.

	Shoes to intermediate rafters	0	1	1	17
	Gangway standards	0	4	3	20
	Ornamental panels	0	8	3	23

Malleable.

	Packings to glazing bars	0	0	1	21
	Weight in one bay	17	9	0	22

For permission to exhibit the contract drawings, the author is indebted to the kindness of Mr. Richard Johnson, M. Inst. C.E., the chief engineer to the Great Northern Railway Company, under whose superintendence the work is being executed.

List of Plates.

Plate 1.—Transverse section of original roof and of other laminated timber roofs.
„ 2.—Elevation and details of original roof.
„ 3.—Roof of the old G. N. R. Station at Bradford.
„ 4.—Elevation of movable staging.
„ 5.—Longitudinal section and details of ditto.
„ 6.—Sections and details of new iron roof.
„ 7.—Details at spandril, ventilators, &c.
„ 8.—Details of purlins.
„ 9.—Sections at ridge, and details of glazing and ladder.

DISCUSSION.

Mr. E. OLANDER said that the roof described was of a type similar to the Great Western and also to the St. Pancras roof. It also approached to some extent the one recently erected over the Agricultural Hall at Kensington. He found in roofs constructed after designs of that class a difficulty in maintenance after completion. There was trouble in painting them, and this entailed great cost. In the Great Western it was the custom to haul up scaffold poles—say four pairs—and to lash them to the ribs, and on these scaffold poles planks were nailed, on which the men worked while scraping and painting. This was a very costly arrangement. The same system had to be carried out in all designs of that class. St. Pancras roof was of the same type, that is to say it was an equilibrium truss in which the line of thrust was in the truss itself. So with the others that he had mentioned. In a roof like the one at Charing Cross there were ties and struts upon which the staging for painting purposes could be placed; but in the case of such a roof as that now described it was difficult to fix the staging. In that respect the three roofs over the Paddington terminus of the Great Western Railway presented similar difficulties. He could not see the necessity for making high roofs. It appeared to be more a matter of custom than of necessity. A high roof of large span seemed to tempt engineers to make something larger, until their increased size carried with it a corresponding and necessarily a heavy cost in maintenance. He would advocate in preference the cantilever design such as was used for a station at West Drayton (of which a sketch was shown), where each platform was covered by an overhanging roof. Although these small roofs had a squat appearance from certain points, they worked satisfactorily, and the cleaning, scraping, and painting could be carried on successfully with the aid of a 12 or 15 feet ladder without any difficulty. The question of maintenance ought to be considered in determining the size of a roof. The very high and closed-in roofs collected smoke and the London fog, and the sulphurous fumes from the engines, so that in a short time they became dirty, and they had to be painted very often. In point of fact at Paddington, by the time that the painters had finished the roof at the far end it was almost time to commence again at the other. He could not see why a roof which answered well at West Drayton, a few miles out of London, should not be as useful in London, where there was so much smoke and fog. It might be said that if this style of roofing were adopted the rain

would come on to the platforms, but if he carried them out in a large station he should raise and widen them considerably and make them more imposing, but always leaving a large free air space for the exit of smoke and other objectionable vapours.

Mr. Francis Campin asked the author whether there was any arrangement in the King's Cross roof for diagonal wind ties.

Mr. Bancroft said there were no wind ties at all.

Mr. A. T. Walmisley said that the record in the Transactions of any large roof construction must be of great value, especially when it was in connection with such a well-known station as the Great Northern terminus at King's Cross. As to the old laminated roof, it was justly thought a great deal of at the time it was made. He could understand how the timbers would decay. No doubt the moisture would work in between the planks, and when the ribs were painted the moisture would be unable to escape, and thus a process of fermentation would be set up. Probably, too, there would have been a difficulty in getting so much timber well seasoned, and perhaps the contractor would have been exposed to the temptation that it was easier to bend the ribs where the wood was somewhat new and unseasoned. The iron roofs which had replaced them were constructed, as the author said, after the type of the Great Northern goods station at Bradford, with the exception that at Bradford the webs of the main principals were pierced in a similar way to those at the Great Western station at Paddington and at the Derby Market Hall. The last speaker had alluded to the roof at King's Cross as being upon the same principle as the St. Pancras roof and the National Agricultural Hall roof. It was only upon the same principle in the fact of its being an arched roof. The St. Pancras roof was an arch of three or four centres. The National Agricultural Hall roof only resembles the King's Cross roof in the division of the main rib above the springing. When the Crystal Palace roof was put up, the ribs there were made of a good depth, to act as girders. He did not think that it was possible to make any arch (unless of very small span) deep enough to act as a girder, considering the unequal pressures that had to be dealt with. The roofs at Paddington were equilibrium arches, but they required very careful setting out, for he believed that they were not circular arches.

Mr. Olander said that they were from three centres.

Mr. Walmisley said that he had always admired the Paddington roof, because the side spans were capable of taking thrusts which came upon them from the centre span. That point was often overlooked in arched roofs of multiple span.

He believed that at the Brighton terminus ties had to be inserted for that reason. The method illustrated by the diagram of temporarily strutting from the travelling stage the arch over the arrival platform, while the arch over the departure platform was being built, was very good. At the joint station which was now being built at Bradford, heavy ties had to be inserted across one span during the erection of the other, and held up with sling rods to the crown. That must be a very expensive piece of work. As to the question of wind bracing, engineers had very different views from what they formerly insisted on. If certain bays were braced, the others could be left to themselves. He supposed that at King's Cross the side walls were so situated and the purlins so connected that the inner bracing for wind pressure was not needed. The tests which had been read by the author appeared to him to be very fair. The contraction of area was certainly preferable as a test to that which engineers formerly required, viz., that the iron must elongate so much per cent. under certain conditions. No doubt the elongation could be more readily measured, as it was a single measurement; but the contraction of area was more constant. The tests were not extravagant. If they increased the standard of breaking weight on the test bar, they might get a stronger iron, but they would lose ductility. As to the question of multiple *versus* single spans, he thought that there was every reason, especially in a railway terminal station, to have a single span if possible. The Victoria Station of the London, Chatham, and Dover Railway was formed in two spans. The central columns were originally placed between the lines of rails. Then it was found desirable to alter the disposition of the platforms, and the result was that the columns now stood in the centre of the narrowest platform, and were in everybody's way. This would not have been the case if there had been but one span.

Mr. OLANDER explained that when he spoke of the roofs being of similar types he was not referring to types of design. He meant, similar in the absence of tie-rods and struts, so that there was no chance of putting up staging for cleaning and painting.

Mr. S. CUTLER said that they were much indebted to the writer of the paper. It appeared to him that the weight of the movable staging was very disproportionately large compared with the permanent work to be fixed. He understood that the weight of the staging was 300 tons, and that of a bay of roofing was only about 17 or 18 tons. He should like to ask why a much lighter platform had not been devised. He thought that Mr. Walmisley's answer to the remarks which had been made

in favour of several small spans in place of one large one was excellent. That is to say, that an engineer never knew what might be required in the future as to the disposition of the platforms. As to convenience of painting, that seemed to him to be a matter which was very often overlooked. The difficulties might easily be avoided, if engineers would pay more attention to the point in designing their work. Another consideration in deciding the size of spans was the comfort of passengers. Persons who travelled knew that the most uncomfortable stations were those which had small roofs, which admitted the rain and all sorts of discomforts. He agreed with Mr. Walmisley in preferring the contraction of area test to the elongation test. The 20 per cent. for flat bars seemed rather a heavy test.

Mr. R. W. Peregrine Birch said there was a great deal of instructive matter in the paper, more than could be all taken in while hearing the paper read. He was looking forward to reading it in the 'Transactions.' He therefore hoped the author would put a few more dimensions upon the drawings before they were handed to the lithographer. He had not caught from the author any statement as to the weight of the roof per square. Information as to the cost of painting, also, would be useful. The paper was a remarkably good one, but these additional facts would make it still more valuable.

The Secretary stated that he had arranged with the author to illustrate the paper when read by diagrams of an exceedingly simple character, but it was never intended that these diagrams should form the basis of the illustrations in the 'Transactions,' which would be prepared from the working drawings.

Mr. J. Bernays said that on the Continent he had seen many wooden roofs of large span. These plank roofs were very light and airy when comparatively small, but when they were of large dimensions they looked very gloomy, as they enclosed such a large volume of space that it was almost impossible to light them up. He would call attention to a very peculiar roof he had seen in Switzerland over a foundry, and had not come across elsewhere. He might, perhaps, best describe its construction by saying that the framing of the inclined surface itself of the roof was made to act as a girder, the ridge and gutter plates being respectively the top and bottom booms, the rafters a series of verticals, and diagonal ties being introduced to take up the tensile web stresses. It was as if girders were laid in pairs across the space to be covered, then inclined, each towards one of the next pair, until their tops touched and rested one against the other. A series of ridge and furrow roofs could thus be formed, self-contained and requiring no separate girders

for their support, and no principals or tie-rods within the covered area. Of course the girders would have to be designed so that the diminished depth due to the inclination should be the basis of calculation for the stresses in the top and bottom booms, and the booms themselves would be designed to forms suitable for their work as ridges and gutter plates. The ends of the bottom booms would also have to be strongly tied, so as to take up the thrust of the inclined framing and covering. The whole covered space would be entirely clear of columns or other impediments, while it would not enclose much empty space in height, and the roofing being transverse, any length of space could be covered by a repetition of the same construction. He thought it would be worth while working out a comparison of cost with the ordinary large span roofs, and if that came out favourable, that the design would have several advantages.

Mr. CUTLER asked what was the span of the roof mentioned by Mr. Bernays.

Mr. BERNAYS replied that it was about 40 or 50 feet. He should much like to know whether a girder roof of that kind would not be advantageous, as it would do away with columns, and at the same time avoid such great unlighted heights.

Mr. PERRY F. NURSEY said that they had heard from the author that the laminated roof which was now being replaced at King's Cross by an iron one, was the invention of Colonel Emy. He believed that Colonel Emy, who was a French military engineer, first proposed that system of roofing in 1817, as an improvement upon the system of Philibert de Lorme, a French architect. De Lorme's system consisted of arched timber ribs formed of planks in short lengths, placed edgeways, and bolted together side by side, so as to break joint. He constructed the original roof of the Halle au Blé at Paris on that principle. It was 120 feet span, and had been replaced by an iron roof, having been destroyed by fire. The roof of the central compartment of the old Pantheon in Oxford Street, 38 feet span, was another example of de Lorme's system.

It was, however, by no means so advantageous a method of construction as Emy's, for it involved waste of material and greater labour cost, besides being a weaker form of rib. Emy's first roof was of about 66 feet span, and was erected at Marac, near Bayonne.* He also designed a roof for the Imperial Riding House at Moscow, 235 feet span. The principal feature in that roof was an arched beam, the ends of which were kept from spreading by means of ties and diagonal bracing. He had in

* This roof is shown on Plate 1.

his possession a tracing of the Moscow roof with full details, taken from a plate in an old work on carpentry by Colonel Emy, but there seemed to be much doubt whether it was ever actually erected. He agreed with Mr. Bernays that there was a great deal of waste space in the large span roofs. When the stations were lighted up at night, much of the light went up into the distance, and was lost, instead of being intercepted and utilised down below.

Mr. J. Barker thought some of the remarks which had fallen from Mr. Olander were important. He had drawn attention to the difficulty of painting roofs of this class. The web plates of the roof under consideration were a quarter of an inch thick, and the lattice bars of some of the purlins were also a quarter of an inch thick. Most of us knew the effect of a London atmosphere on wrought iron, when not properly painted. He had made a series of experiments on the subject, by exposing plates of iron on the top of a roof in a very exposed situation for twelve months, and had watched the action of the weather upon them. The quantity of scale which came from a piece of unpainted steel or wrought iron in two months was almost incredible. The difficulty and expense of painting a roof of the kind which had been described were very great, and railway companies were so busy that they might possibly overlook the necessity of the painting for an indefinite period. A thickness of $\frac{1}{4}$ inch did not allow much margin for diminution by rusting. He had recently seen on a broad web plate rust $\frac{3}{8}$ in. thick, on a bridge now in use, which had not been painted for many years. The scantlings were reduced from $\frac{3}{8}$ inch thick to a thin shell. With respect to wind ties, it was stated in the paper that the purlins would do this work. He admitted that if the wind struck the roof longitudinally the purlins would act, either in compression or tension. But if a side wind struck the end of the roof at right angles to the length, diagonal wind ties were generally needed to convey the force of the impact from one principal to the next, and so on, so as to cause them to act together. In that case the purlins would be of no use, and the side walls and covering would have to do the work. It was, however, in his opinion better to have diagonal wind ties at three places, say, in two or three bays at each end, and near the gutters along each side; the resistance to wind could then be definitely calculated, and not left to conjecture.

Mr. J. H. Cunningham said that he had no doubt that the designers of the roofs at Paddington, St. Pancras, and Olympia, had adopted the arch-rib type for reasons which were good in these particular cases. Still he could not help thinking that in general a truss was a better form for a large roof than any

arched rib, because the calculated stresses were more likely to agree with the actual ones in a truss than in an arched rib. It was better, if possible, to adopt some simple form of truss, as had been done at Charing Cross and Cannon Street, and at Lime Street, Liverpool, than ribs like those that had been referred to, because the estimated values of the trusses were much more reliable and satisfactory in structures of the former than in those of the latter type. If in any case the arched rib seemed the best form to adopt, either on account of its architectural effect or for other reasons, the stresses might be simplified and defined by hinging the rib at the crown and at the supports, a device which had been adopted in two large railway station roofs in Berlin.

Mr. J. W. Wilson, jun., said that the question of the construction of a large station roof without interference with the traffic beneath, carried one back to the erection of the New Street Station roof at Birmingham, which was carried out under the direction of Robert Stephenson. When the instructions for that work were given, Mr Stephenson was told that such a roof could not be made, nor could it be erected in the manner proposed. He, however, persisted, and it was carried out successfully. It would not be out of place to take this opportunity of protesting against the statement made recently by an architectural professor, that engineers had no idea of beauty. Engineers and architects looked at beauty, perhaps, from different points of view; but he thought that it could not be denied that there was a great deal of beauty of its own kind in such roofs as those of St. Pancras and Olympia. No doubt it was tempting to use such light sections as those shown to-night, but he should be glad to know whether any of those present had any experience of the length of life of such thin material. The question of accessibility was, under any circumstances, of great importance. Mention has been made of snow. It was now the opinion of many engineers that its effect had been underrated. In text-books, snow was put down at all sorts of weights varying from 5 lbs. per cubic foot, to over 30 lbs. In an American work it was quoted at the very remarkable weight of 65 lbs. per foot. Although it might be supposed that snow would easily slide off a roof, that was not always the case. American engineers said that English engineers did not make enough allowance for snow, and the past winter had certainly been productive of accidents to roofs from this cause, which would bear out this contention. In the case of such a roof as that proposed by Mr. Bernays, the snow might fill the furrows to a considerable depth in a very short time, and it was obvious that the lower layers would be very much consolidated, causing great "accidental stress" upon the structure. It certainly had surprised him to hear that

there were no wind ties in the roof described in the paper, though special circumstances might warrant such an arrangement. At the Crystal Palace there were several cases where wind and other ties had been long ago removed, but their absence did not appear to have affected the structure at all.

Mr. R. J. READ wished to add his testimony to the value and interest of the paper which Mr. Bancroft had put before them. A former speaker had called attention to a point which must have struck others, namely, the great weight of the staging compared with the weight of the rib which had to be erected from it; but it must be apparent that the weight was a great advantage in permitting the side wall to be strutted against it. It should be remembered also, that the contractors had to adopt the same method and use the same girders which were used in erecting the other span. Several gentlemen had spoken about maintenance and the difficulty of painting, and had classed this roof and the Paddington roof and the Olympia roof all together. But there was a great difference in the facility of painting in the various roofs, on account of differences in the detail of the ribs. The Great Northern roof and the Paddington roof were plate ribs. The St. Pancras roof and that at Olympia were lattice ribs. Any one could see that it was easier to construct a scaffolding upon the lattice than upon the plate ribs. As regarded terminal stations, the great London termini might require to be altered on account of the growth of the traffic, necessitating a fresh arrangement of the platforms, and in such a case columns might become a nuisance. But many large span roofs existed at through stations, as might be noticed on the Great Western Railway at Oxford, Banbury, and Westbury. Persons who had had to wait at those stations must have noticed the difference between the temperature there and the temperature at small stations with "umbrella" roofs. In his opinion the through stations were simply flues, and the wind blowing through made them almost unbearable. As to Mr. Helliwell's glazing, it was being used on some roofs at the new goods station of the Midland Railway at St. Pancras, and there Mr. Helliwell had adopted bars of zinc or some compound metal, whereas the bars in the roof described by the author were of wrought iron. Perhaps Mr. Helliwell would state what advantage he anticipated, and give them some information as to the system generally, and as to prices per super foot.

The PRESIDENT said that Mr. Helliwell had left the meeting, but it might be arranged to add some details in the form of an appendix.

Mr. R. M. BANCROFT, in replying to the various questions raised during the discussion, said that his part had been ren-

dered much easier by the various speakers having to a great extent answered each other. The value of the paper consisted in its being a practical record of how a large and important station roof had been renewed in iron without interference with the regular daily passenger traffic of the terminus—a most important desideratum. One member had observed, it was easier and cheaper in erecting, painting, &c., to cover each platform of a station with a small span roof, leaving the lines of rails uncovered as in the case of "island platforms," than to have one large span from wall to wall. In the case of terminal stations other considerations besides maintenance had to be thought of, the most important being the comfort of the travelling public. It frequently happens that passengers have to wait a considerable time, and he did not regard it as an unnecessary expense to entirely cover an important station. In a busy railway station columns were undoubtedly in the way, and in times of rain, wind, and snow, if the platforms only are covered, the passengers must always be subjected to inconvenience and annoyance. In the case now before us, the renewal of King's Cross station roof, the engineer was bound by the existing lines of rails, buildings, &c., as explained in the paper, to alter which would have been very inconvenient, besides causing needless expense. In the repairs and painting of the eastern arcade roof there had not arisen any great difficulties such as it had been imagined would exist, scaffolders and workmen accustomed to work at great heights and used to climbing had been employed and no trouble had been experienced.

The travelling stage for the renewal of roof was heavier, no doubt, than would be required in constructing an entirely new one, but in this case it was imperative that the rails and platform must be kept free for the traffic, and protection for the passengers must also be provided, so that no falling rivets, bolts, timber, or other materials should injure those passing underneath, and it was considered better to provide for these likely contingencies than to run the risk of having claims for compensation. A most important office, also, was filled by this staging in taking the whole of the thrust from the roof over the eastern side, when the timber principals were removed; the weight of the staging supplying all the resistance necessary, and only very simple strutting being used as described in the paper, thus not entailing unsightly and costly ties being stretched across the eastern arcade, as would have been otherwise necessary.

He did not consider the scantling of the iron web, flanges of main rib, or lattice bars of the purlins too small if they were

properly painted at intervals; the eastern arcade roof had been painted three times in about nineteen years, viz. in August 1873, July 1880, and June 1885; the cost averaging to the present time about 100*l.* per annum, and to all appearances the ironwork was now as good as when first erected, no appreciable deterioration by rust having taken place.

As regards wind bracing, the station being protected at the south end by a wall and clock tower, at the north end by the framing to roof, and a large station foot bridge connecting the arrival and departure platform, and on the west side by a block of offices, it would have been a waste of material to have provided wind ties. The old laminated timber roof had stood about thirty-six years, and the eastern arcade renewal in iron for about nineteen years; both had answered the purpose for which they were erected, and in neither case had wind bracing been used, showing clearly it was not required.

With respect to the density of snow, on the 11th January, 1866, a superficial foot 6 inches thick was taken from the western arcade roof and found to weigh 16 lbs.

The weight of one old laminated timber rib is about 3 tons 12 cwt., and of one new wrought-iron rib 6 tons 17 cwt. 3 qrs. The weight, per square, of ironwork in new roof is about 16 cwt. 2 qrs.

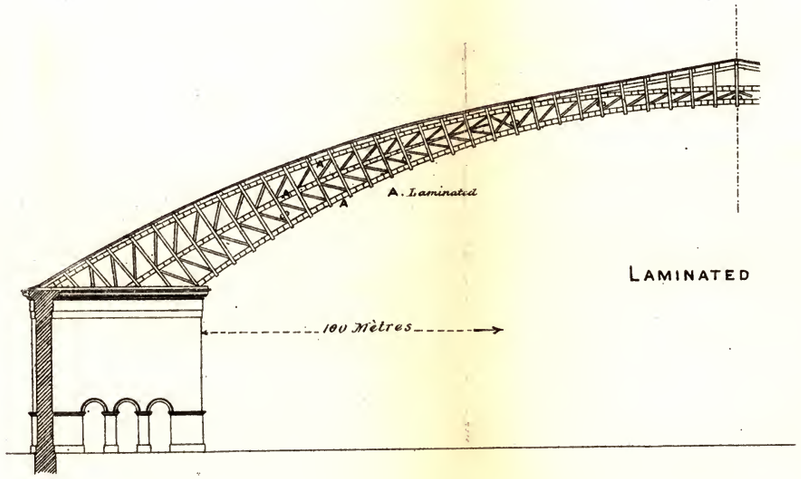
The following particulars respecting his system of glazing were afterwards supplied by Mr. T. W. Helliwell.

The patent glazing bar which has been adopted for the louvre roof at King's Cross is of rolled iron, but may also be made in steel. It was designed chiefly with a view to meeting the requirements of the engineer as regards strength for a long bearing, and for forming a constructive part of the roof. This necessitated a special section, which presented great difficulties in rolling. The zinc bar referred to by Mr. Read is no new departure, but has been employed from the first. The Olympia roof and many others are so glazed. In cases where the zinc bar is required to be in long lengths (say, over 6 feet) it is strengthened with a T-iron core, or, if preferred, it can be mounted on a wooden sash bar.

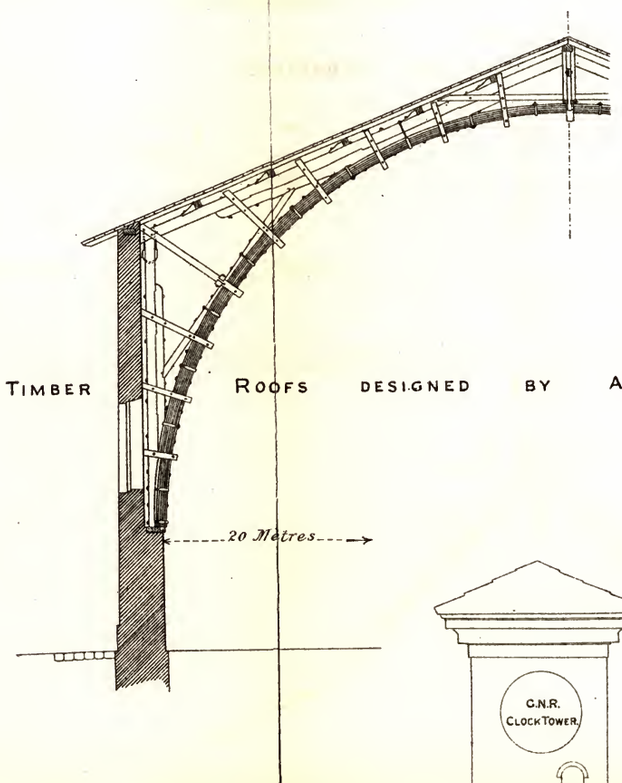
Prices vary according to design of roof and the area to be covered, but are approximately from 1*s.* to 1*s.* 3*d.* per superficial foot, for $\frac{1}{4}$-inch rolled or rough-cast plate-glass and bars, &c., including fixing.

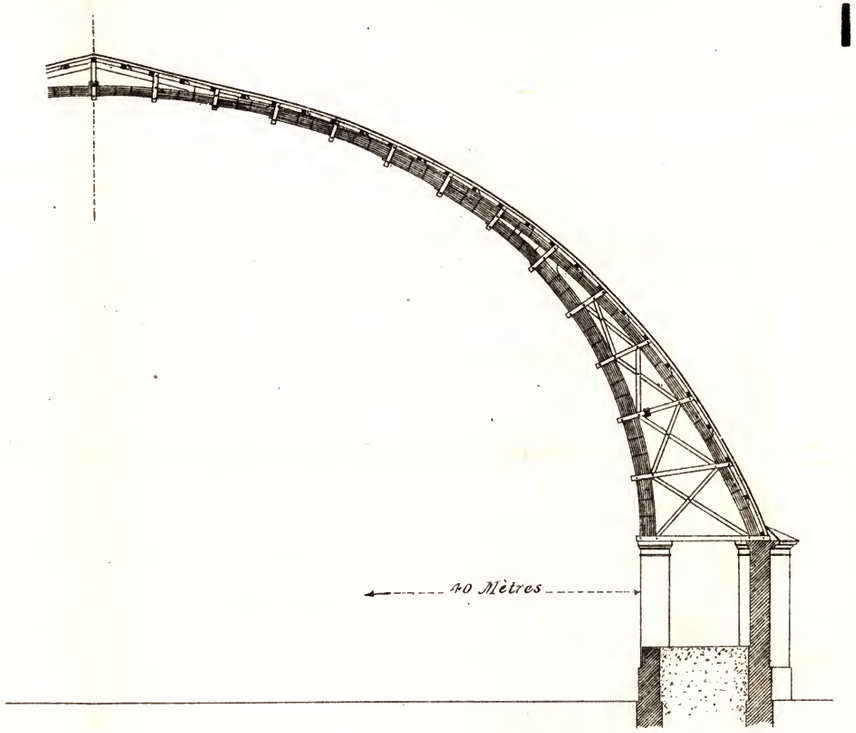
LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

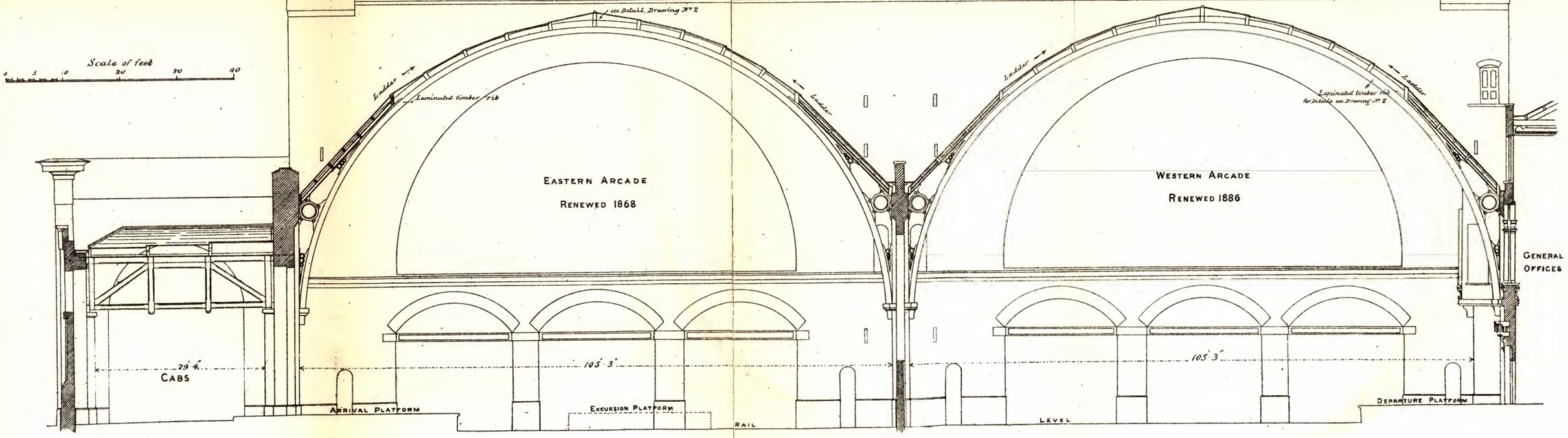
G.N.R. KING'S CROSS STATION . RENEWAL OF ROOF OVER DEPARTURE SIDE



LAMINATED TIMBER ROOFS DESIGNED BY A.R.EMY







TRANSVERSE SECTION AS ERECTED 1850–2

Looking South.

F.J.BANCROFT

E & F. N. Spon, London & New York.

LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

2

PART ELEVATION OF RIB *shewing the number of laminated boards and mode of diminishing same*

SECTION OF W.I. GLAZING BAR

Dotted line shews extent of rust in 35 years.

Iron strap for connecting purlins 5'0" x 3" x ⅜"

PART OF RIB AT PURLIN A

ELEVATION

1 wrought one side and beaded casing to purlins

Cast iron purlin shoes

SECTION

5"x3" Gutter bearers (¼ grade)

SECTION THRO' POCKET B B.

Spandril Casting built into wall.

PLAN OF CENTRE WALL (over Arched openings)

DETAIL OF LOWER PORTION OF RIB *shewing termination of top part of laminated boards*

Glazed with rough plate glass in sheets 8'6" x 2'6"

Ribs 20'0" apart centre to centre.

Head capping

Glass ⅜ thick

DETAIL OF RIB AT RIDGE – ELEVATION AND TRANSVERSE SECTION

DETAIL OF SPANDRIL CASTING *Built into Wall.*

Shews thro' Centre Wall in one casting.

Corbels in one stone thro' Centre Wall

SPANDRIL FILLING *at Base*

G.N.R. KINGS CROSS PASSENGER STATION ROOF. ERECTED 1850-2

ELEVATION AND DETAIL OF OLD RIB

Scale to Elevation 1 2 3 4 5 10 15 feet

Do " Details 1 2 3 4 5 feet

F.J. BANCROFT

E. & F.N. Spon, London & New York.

2

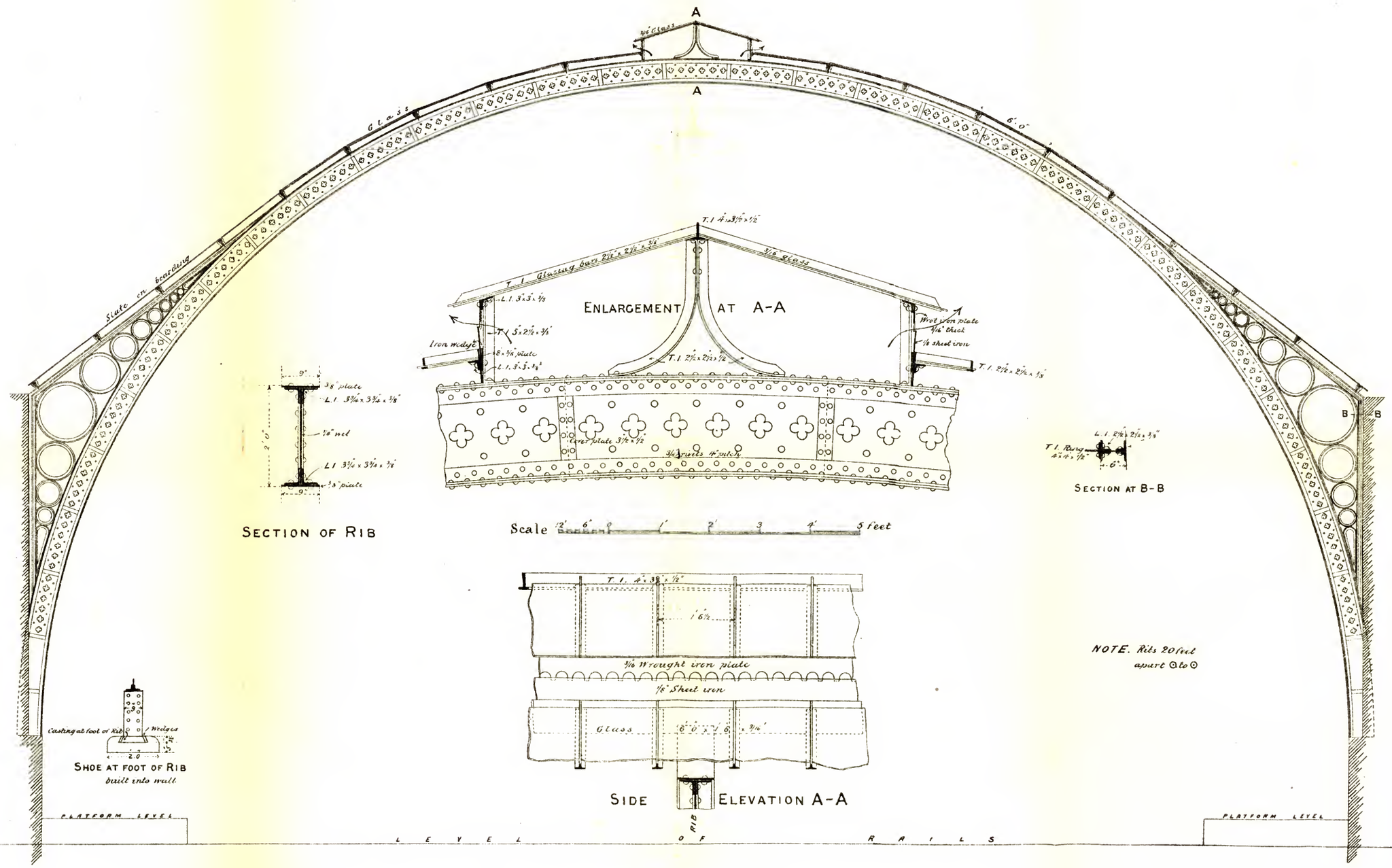
LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

KING'S CROSS ROOF BY R.M.BANCROFT

3

ROOF OVER G.N.R. GOODS STATION BRADFORD

Scale 0 1 2 3 4 5 10 15 20 feet



ENLARGEMENT AT A-A

SECTION OF RIB

SECTION AT B-B

Scale 12" 6" 0 1' 2' 3 4' 5 feet

SHOE AT FOOT OF RIB
built into wall

SIDE ELEVATION A-A

NOTE. Rib 20 feet apart ⊙ to ⊙

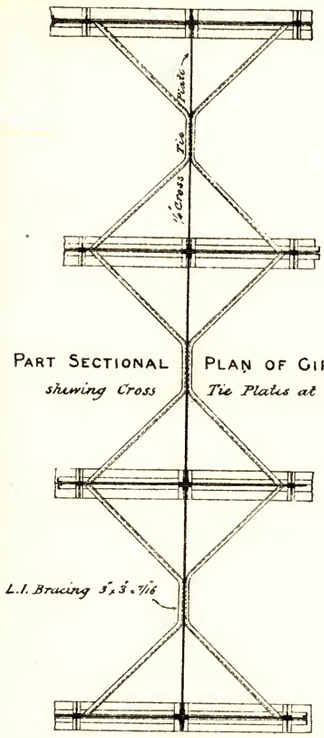
F.J.BANCROFT

E & F.N. Spon, London & New York

LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

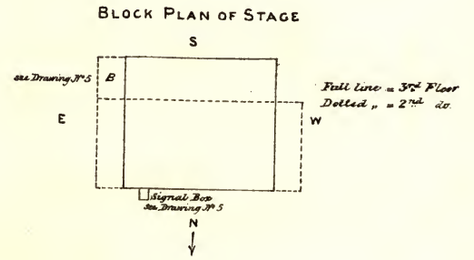
G.N.R. KING'S CROSS STATION — RENEWAL OF ROOF OVER DEPARTURE SIDE — 4

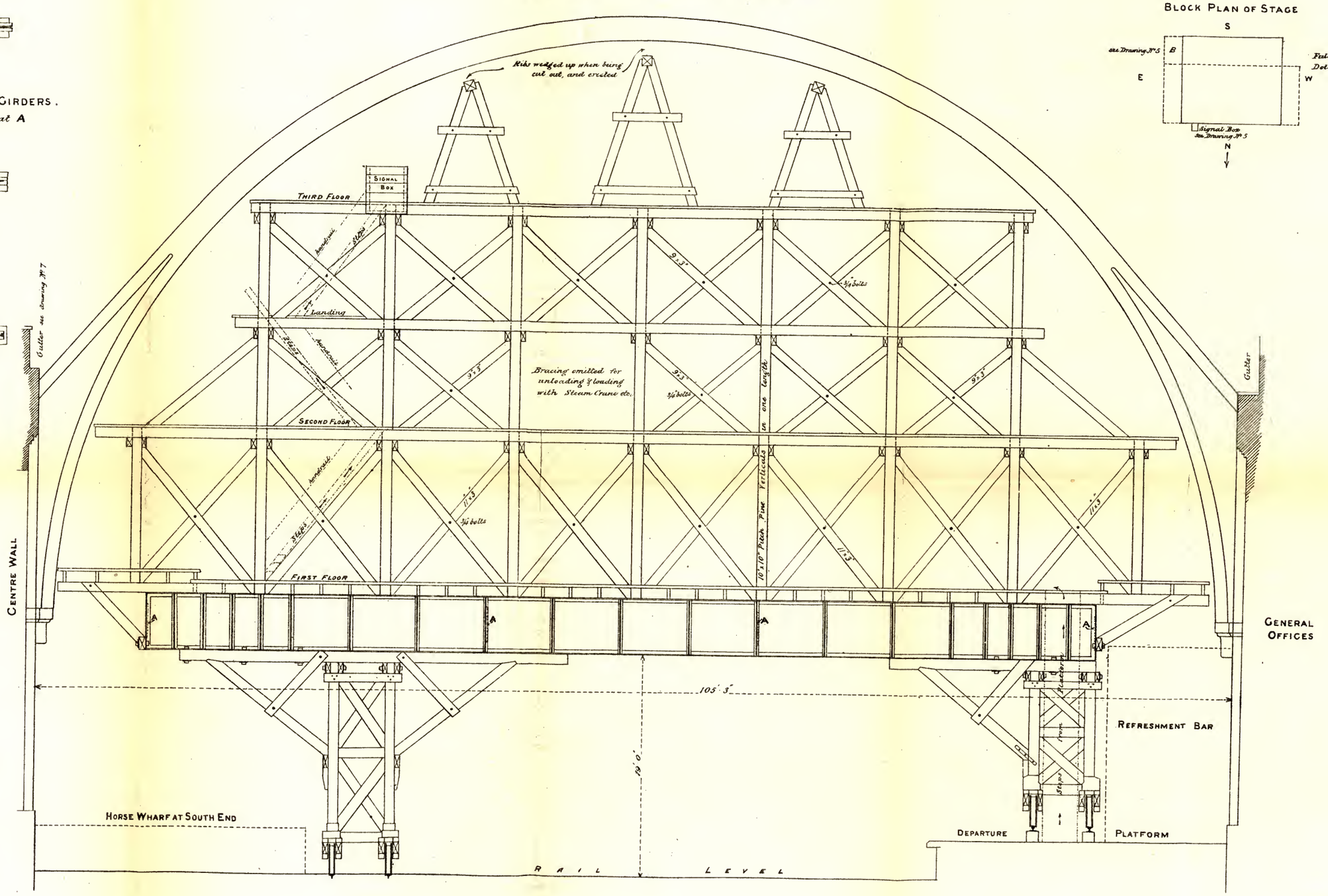
MOVEABLE STAGE



PART SECTIONAL PLAN OF GIRDERS.
shewing Cross Tie Plates at **A**

Scale of 0 5 10 15 20 feet





ELEVATION

Looking South.

F.J. BANCROFT

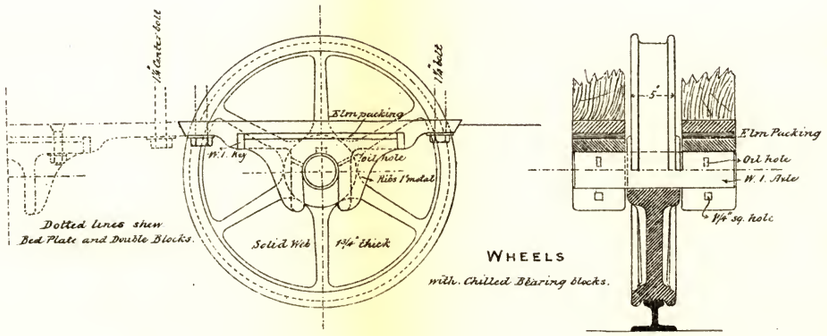
E. & F. Spon, London & New York.

LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

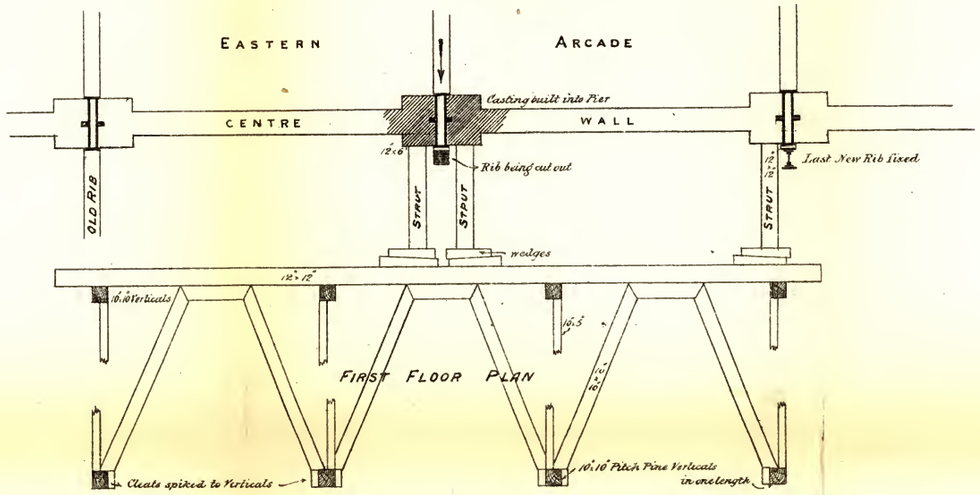
G.N.R. KING'S CROSS STATION RENEWAL OF ROOF OVER DEPARTURE SIDE 5

MOVEABLE STAGE

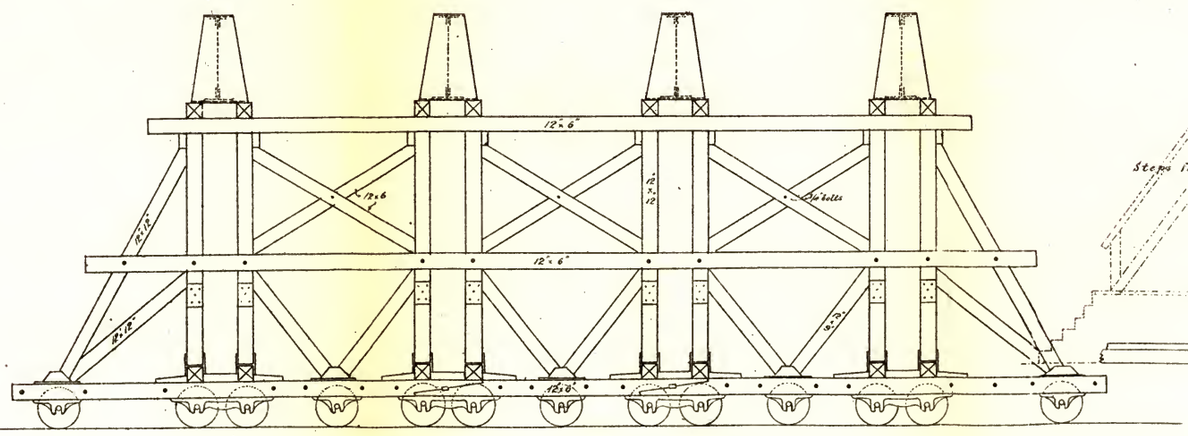
Scale of 0 5 10 15 20 feet



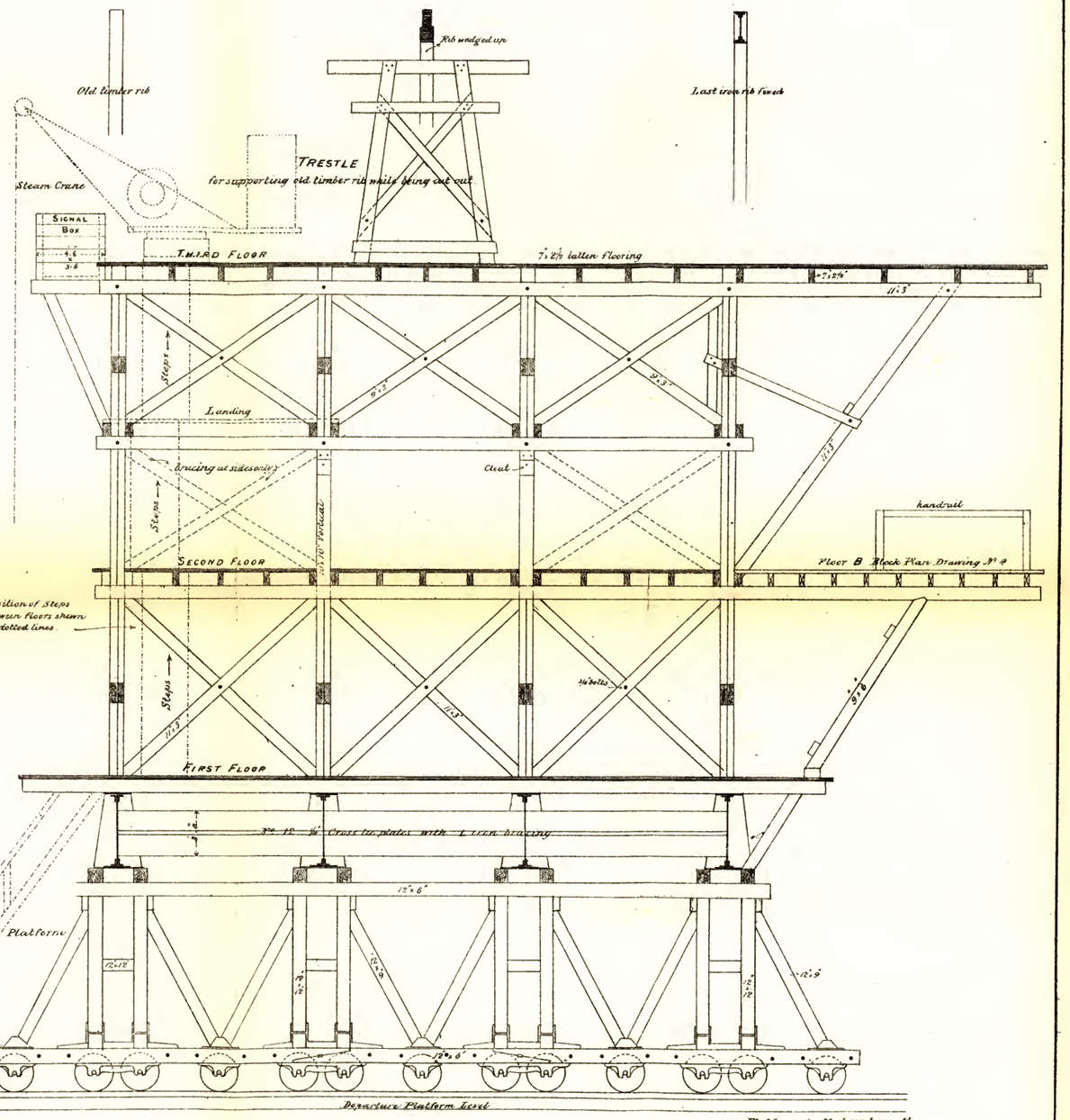
WHEELS
with Chilled Blearing Blocks.



STRUTTING TO CENTRE WALL
During removal of old timber rib



SIDE ELEVATION OF TRESTLE ON RAILS



LONGITUDINAL SECTION OF STAGE
Looking West for Trestles on Platform.
do. East for Superstructure.

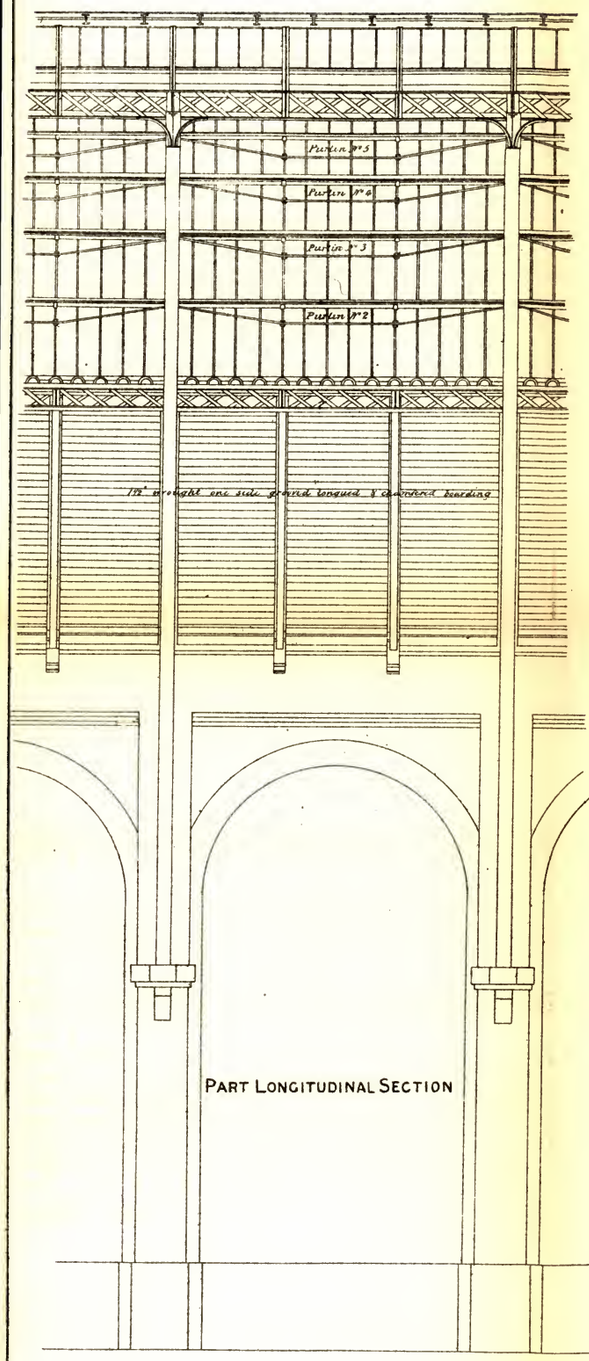
F.J. BANCROFT

E. & F. N. Spon, London & New York.

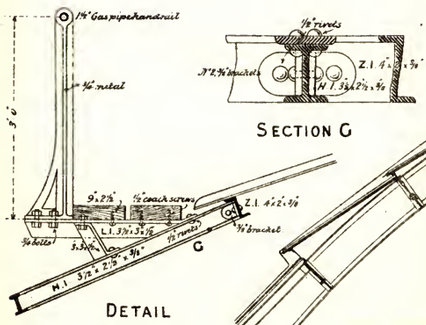
LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

G.N.R. KING'S CROSS STATION. RENEWAL OF ROOF OVER DEPARTURE SIDE

6

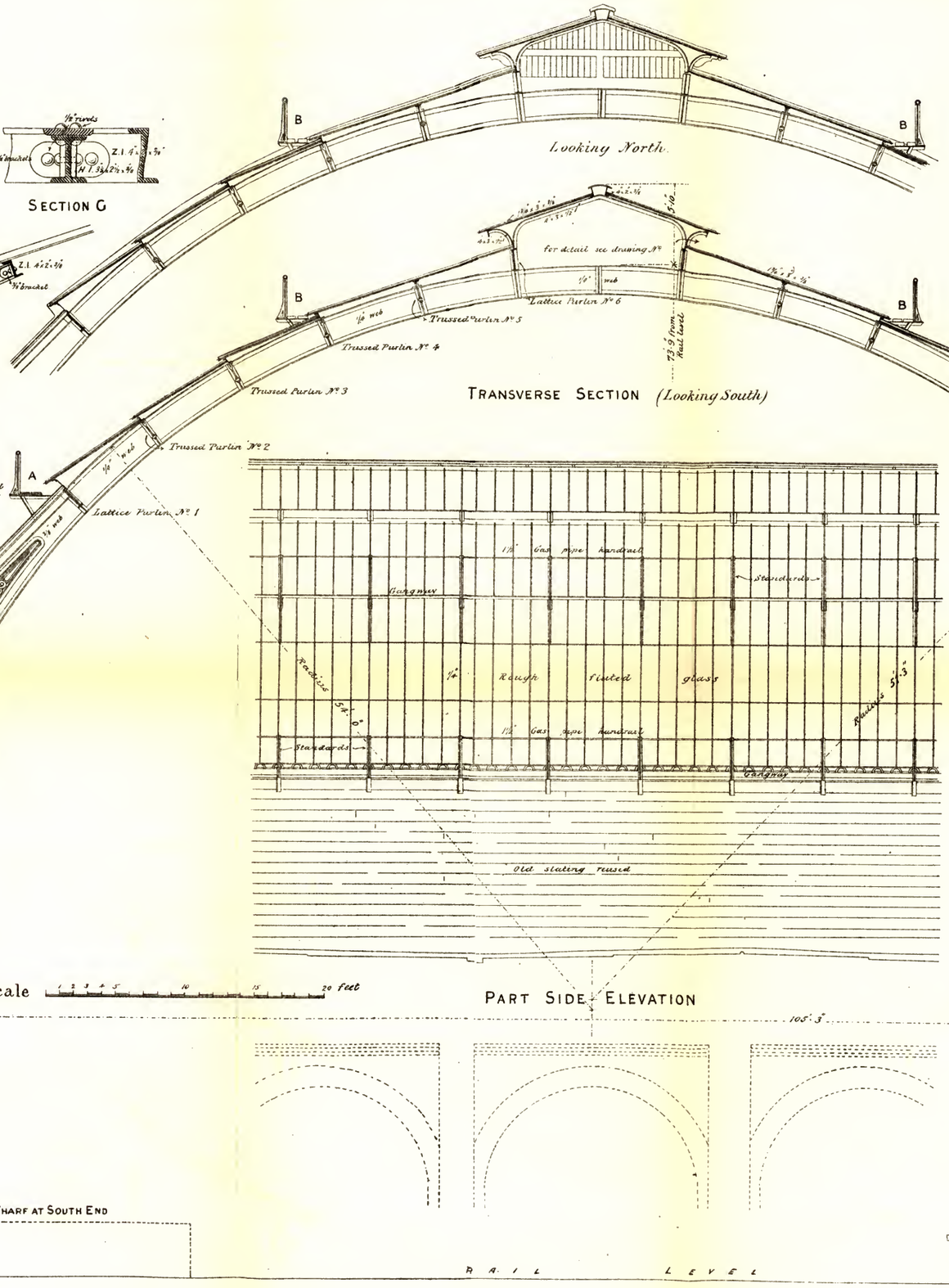


PART LONGITUDINAL SECTION

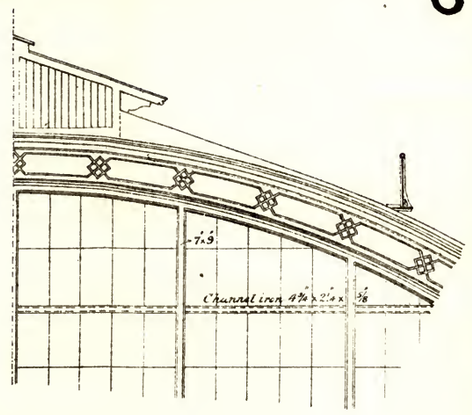


DETAIL OF GANGWAY B.

SECTION G



TRANSVERSE SECTION (Looking South)



ELEVATION OF NORTH END

Scale 1 2 3 4 5 10 15 20 feet

PART SIDE ELEVATION

105'3"

Ribs 20'0" apart centre to centre.

HORSE WHARF AT SOUTH END

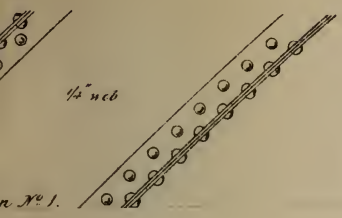
DEPARTURE PLATFORM

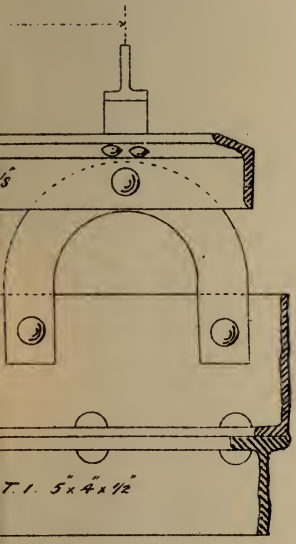
RAIL LEVEL

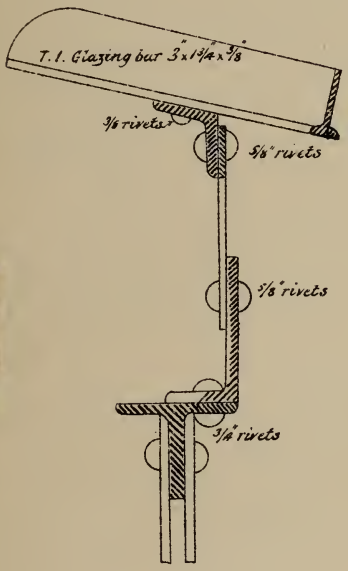
F.J. BANCROFT

E. & F. N. Spon, London & New York.

7







ENTILATION OPENING

4 5 feet

1 foot

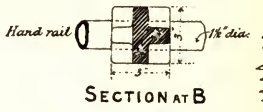
F. J. BANCROFT

7

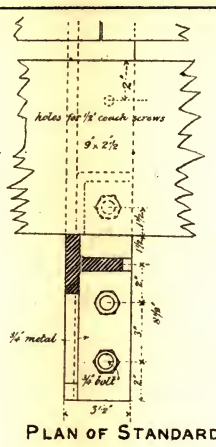
G.N.R. KING'S CROSS STATION

RENEWAL OF ROOF OVER DEPARTURE SIDE

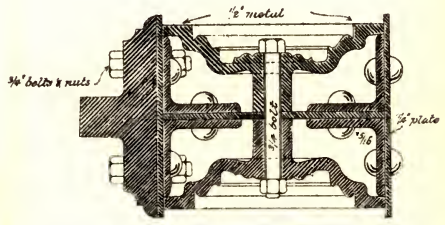
DETAILS



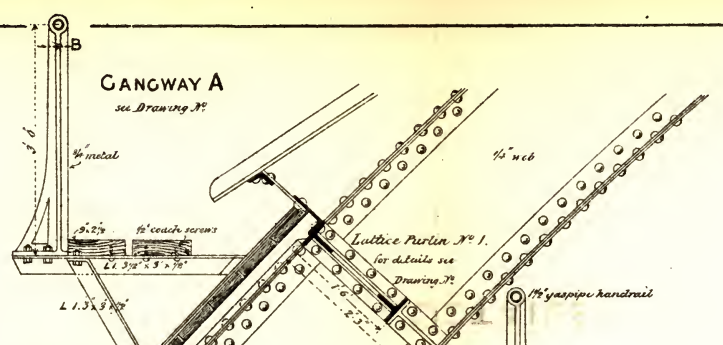
SECTION AT B

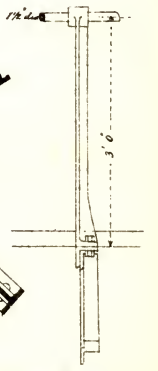


PLAN OF STANDARD



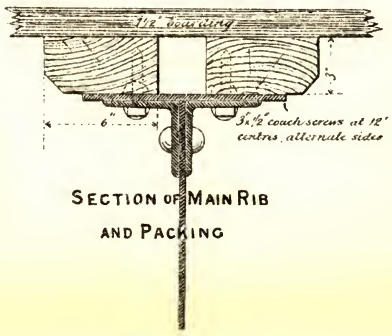
SECTION AT A A





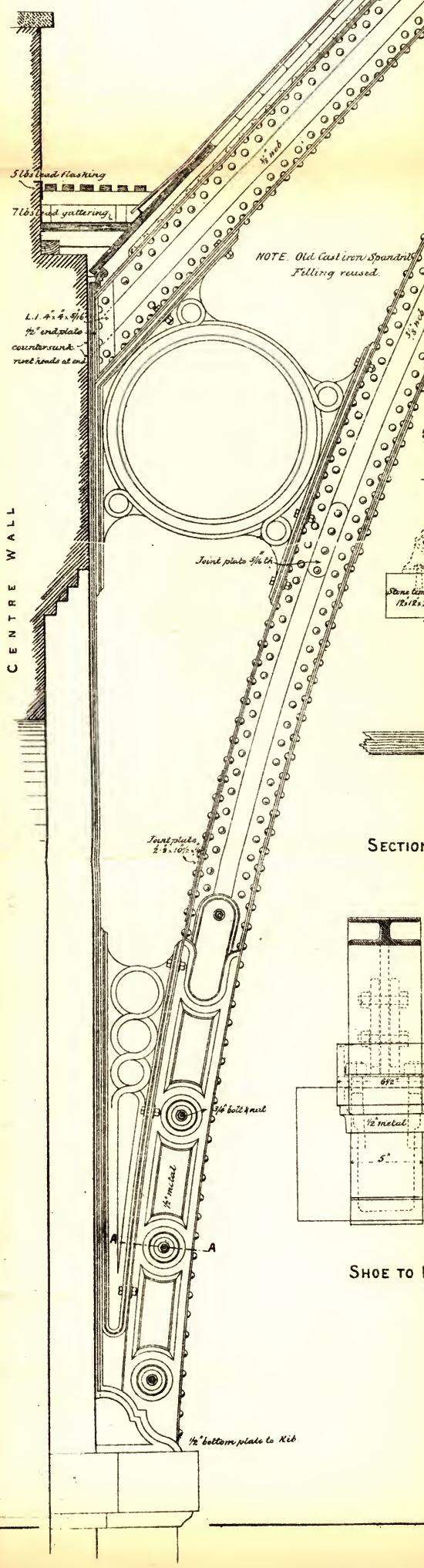
FRONT ELEVATION OF STANDARD

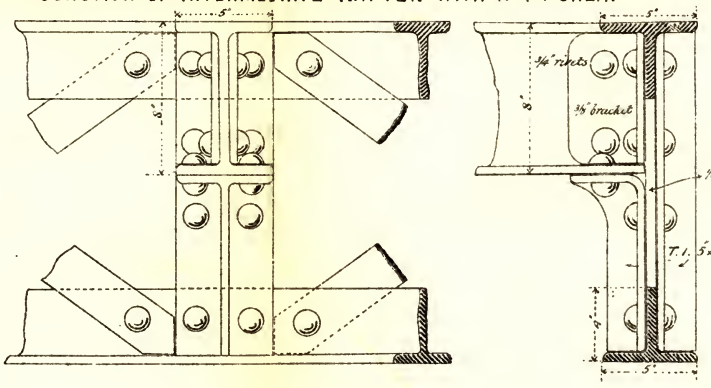
1½ IN: SLATE BOARDING

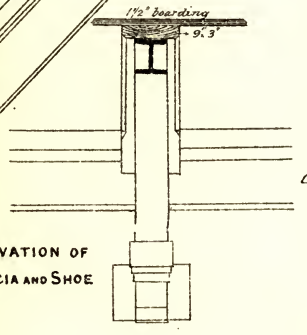


SECTION OF MAIN RIB AND PACKING

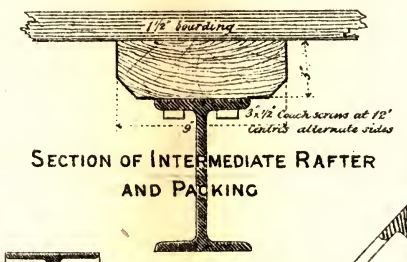
INTERMEDIATE RAFTER



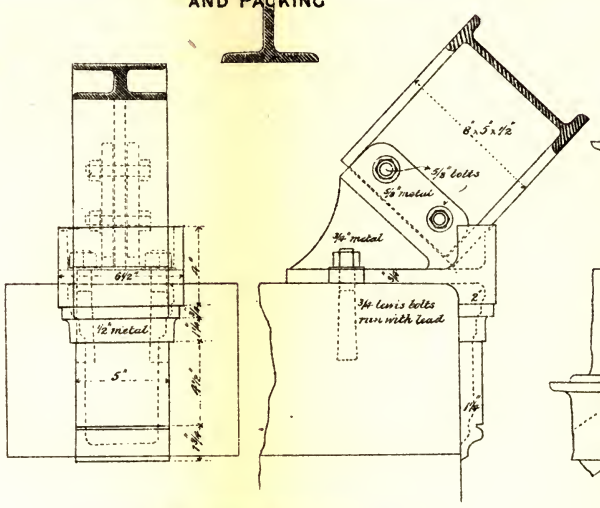




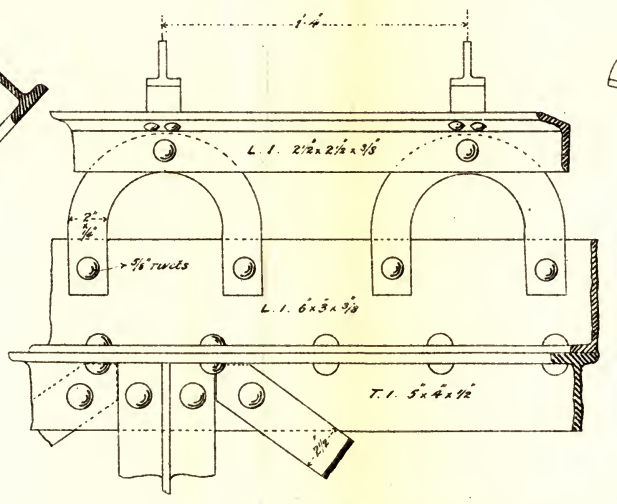
ELEVATION OF FASCIA AND SHOE



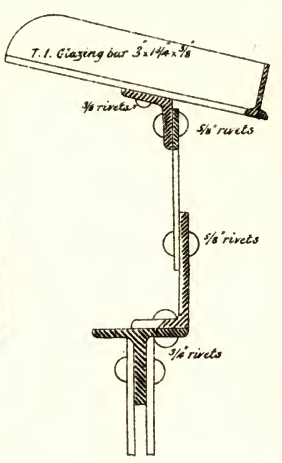
SECTION OF INTERMEDIATE RAFTER AND PACKING



SHOE TO INTERMEDIATE RAFTER



HORSE SHOE VENTILATION OPENING



General Scale. 12" 6" 0 1 2 3 4 5 feet

Scale to Enlargements 12" 9" 6" 3" 0 1 foot

F.J. BANCROFT

E & F.N. Spon, London & New York.

8

KIN

LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

8

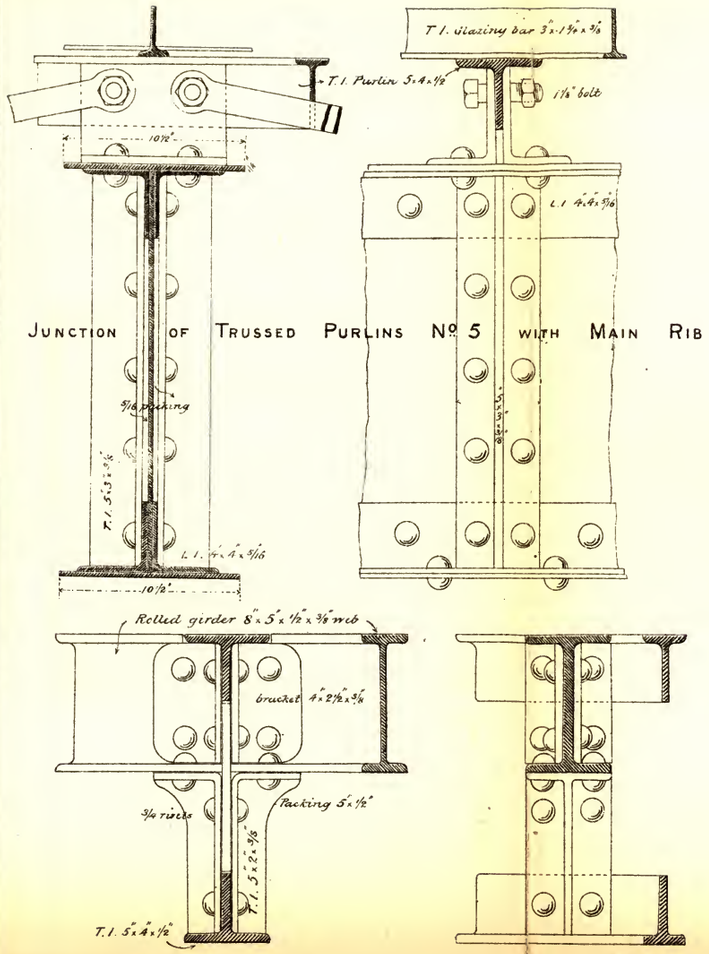
G.N.R. KING'S CROSS STATION.

RENEWAL OF ROOF OVER DEPARTURE SIDE.

DETAILS OF PURLINS.

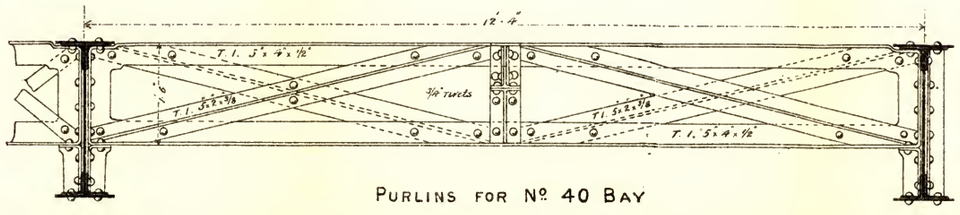
General Scale, 12" 6" 0 1' 2 3 4 5 feet

Scale to Enlargements 12" 9" 6" 3" 0" 1 foot

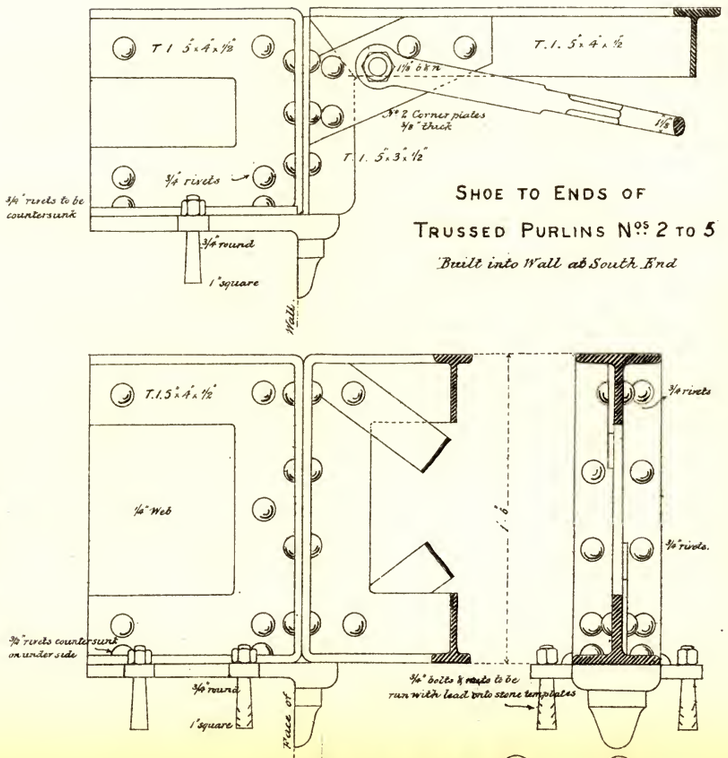


JUNCTION OF TRUSSED PURLINS No 5 WITH MAIN RIB

JUNCTION OF INTERMEDIATE RAFTER WITH PURLINS No 40 BAY



PURLINS FOR No 40 BAY

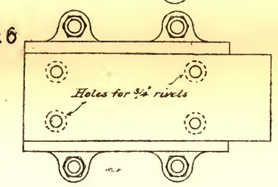


SHOE TO ENDS OF TRUSSED PURLINS Nos 2 TO 5

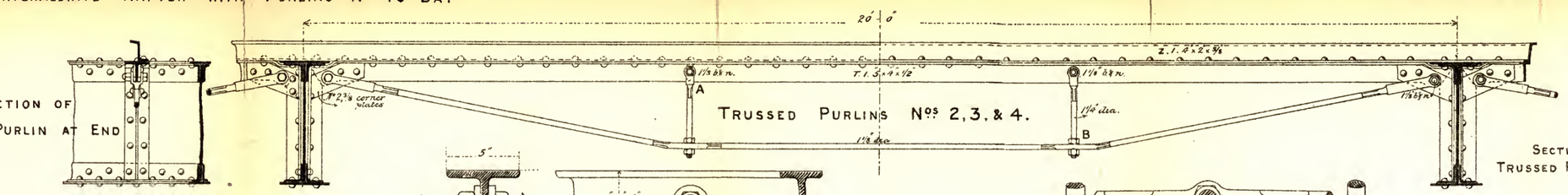
Built into Wall at South End

SHOE TO END OF PURLINS Nos 1 & 6

Built into Wall at South End.

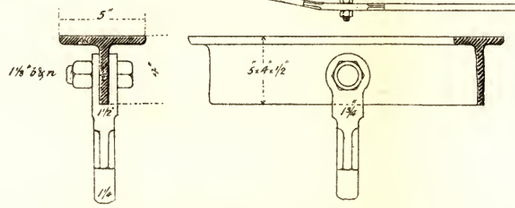


PLAN OF SHOE

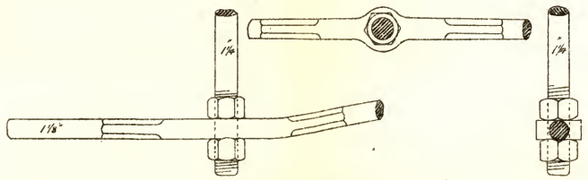


TRUSSED PURLINS Nos 2, 3, & 4.

SECTION OF TRUSSED PURLIN AT END

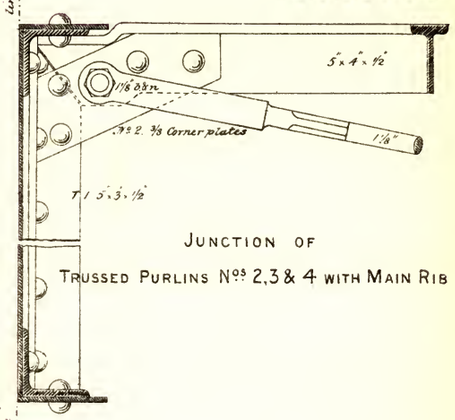


ENLARGEMENTS AT A

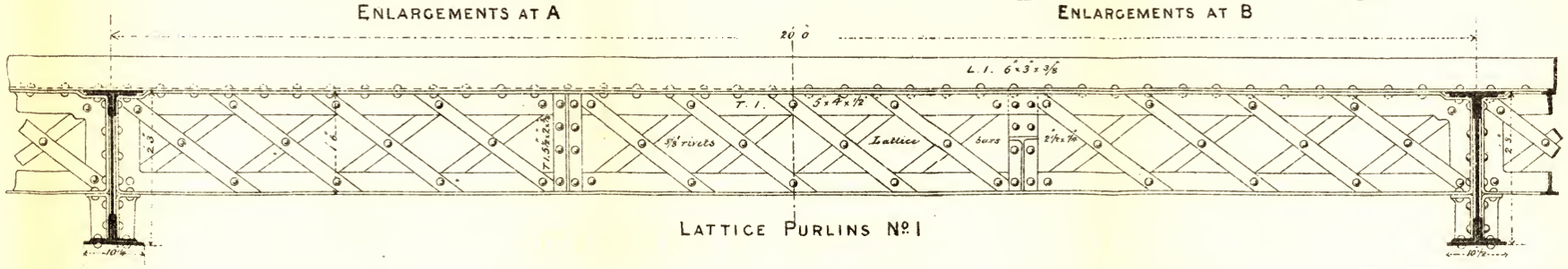


ENLARGEMENTS AT B

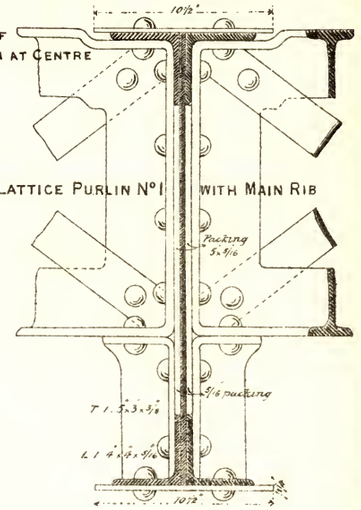
SECTION OF TRUSSED PURLIN AT CENTRE



JUNCTION OF TRUSSED PURLINS Nos 2, 3 & 4 WITH MAIN RIB



LATTICE PURLINS No 1



JUNCTION OF LATTICE PURLIN No 1 WITH MAIN RIB

F.J.BANCROFT

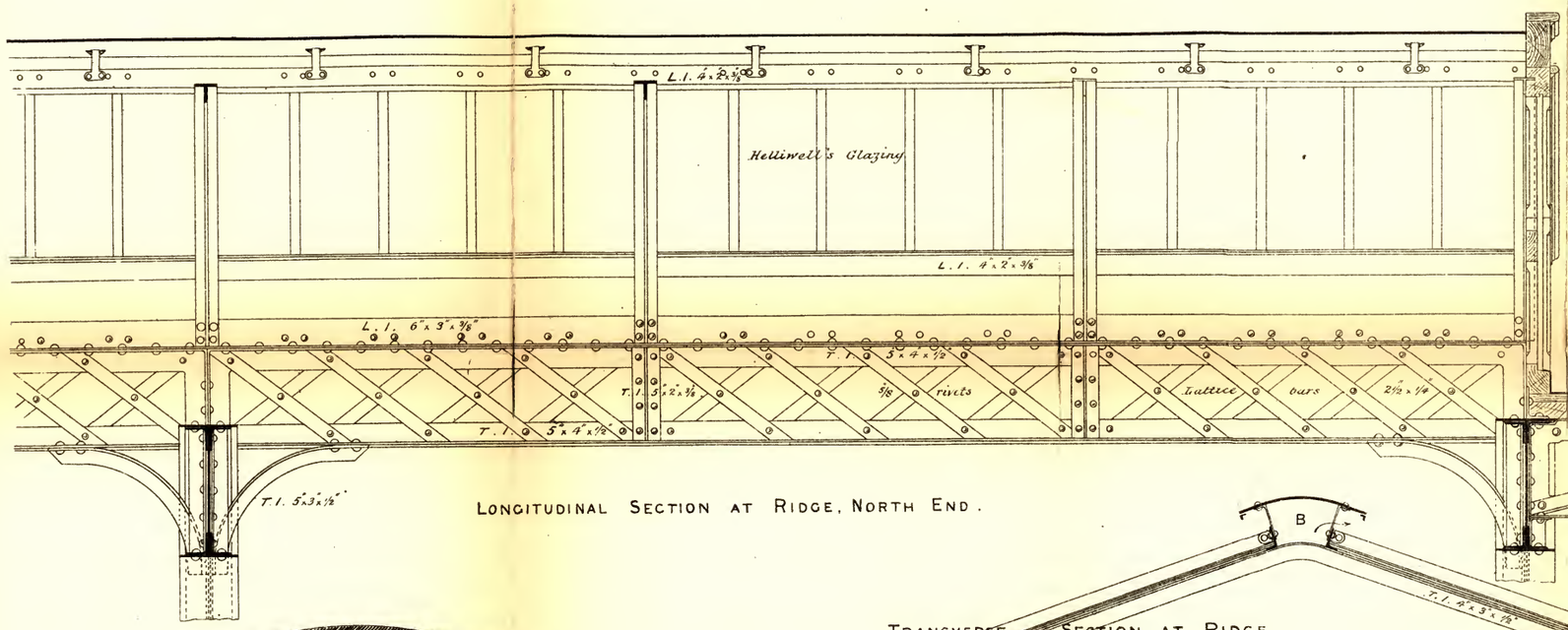
E & F N. Spon, London & New York.

LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

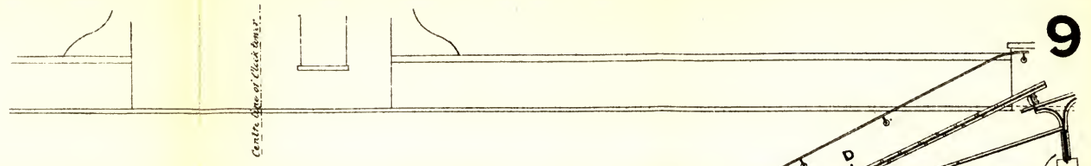
G.N.R. KING'S CROSS STATION

RENEWAL OF ROOF OVER DEPARTURE SIDE

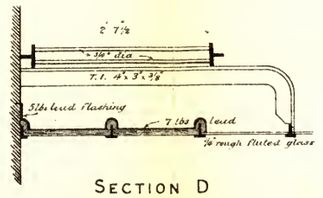
DETAILS.



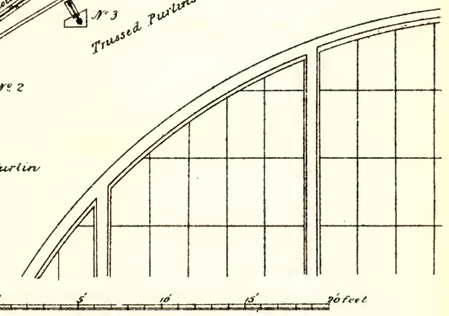
LONGITUDINAL SECTION AT RIDGE, NORTH END.

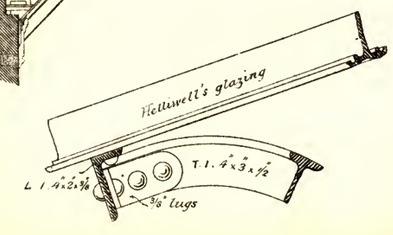


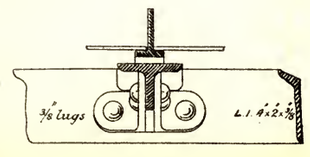
LADDER AT SOUTH END



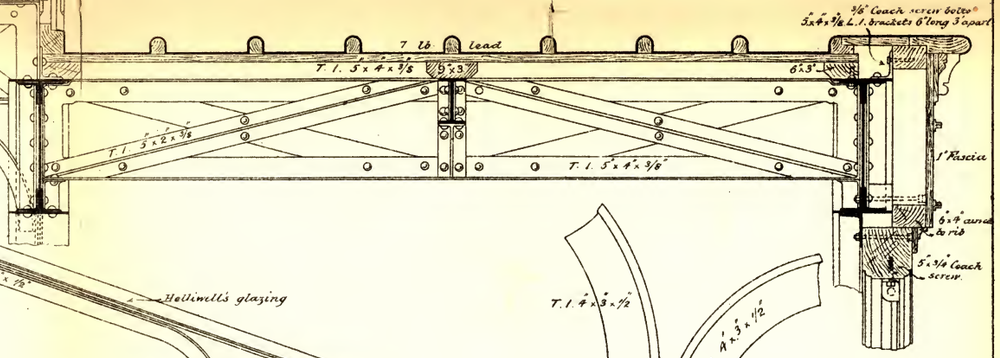
SECTION D

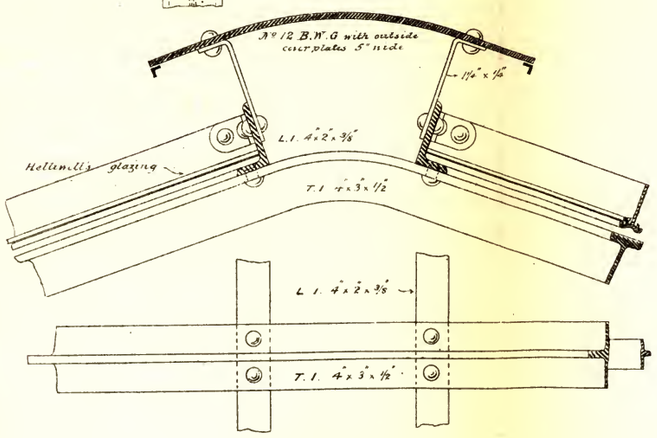




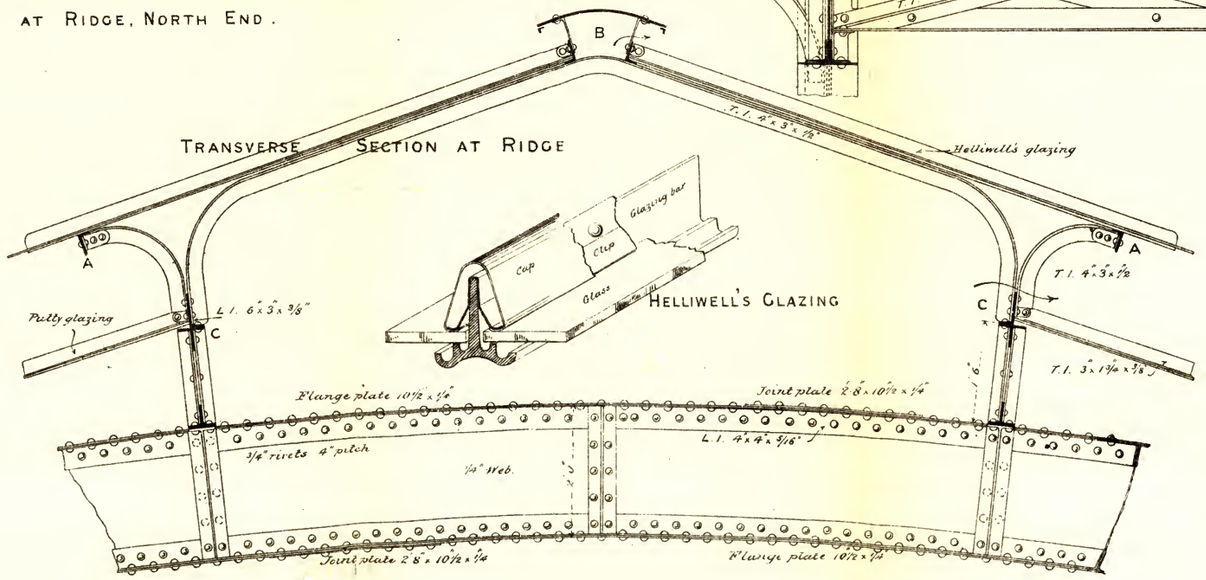


ENLARGEMENTS AT A

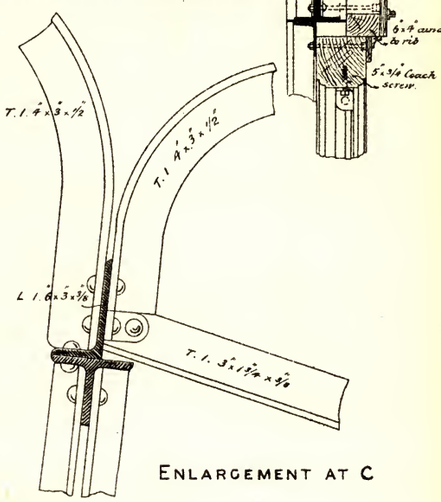




ENLARGEMENT AT B



TRANSVERSE SECTION AT RIDGE



ENLARGEMENT AT C

F.J.BANCROFT

E. & F.N. Spon, London & New York.

VACATION VISITS.

THREE visits were carried out in the summer and autumn of 1887. The first was on Wednesday, the 15th of June, to the works of Messrs. Aveling and Porter, at Rochester. The members and their friends reached Rochester about 2 p.m. by the South-Eastern Railway, and were most cordially received and entertained at his house by Mr. Aveling, under whose personal guidance and that of Mr. S. Aveling they afterwards inspected the works. The general character of the establishment is so well known that a detailed description is unnecessary. The points that attracted most attention were the forging of the crank shafts, which was effected by hydraulic pressure in two heats, the process being rapid and remarkably accurate in its results. Tweddell's hydraulic riveters were at work on the boiler shells, and an ingenious machine which drilled and tapped at one run through both boiler-shell and fire-box, screwed holes for the stays. The holes for the brasses of the journals were also being bored on both sides of the side-frames at the same time by a special machine, so as to be in perfect line. After visiting the foundry and erecting shop, the party proceeded to the yard, where several finished engines were standing, three of which were put through their paces. The first was a fine 18 horse-power ploughing engine, one of a pair being made for the South of France for breaking new land for vine cultivation, the ground being ploughed to a depth of from 21 to 24 inches. The cylinders were 9-inch diameter and 12-inch stroke, and the steam pressure 120 lbs. The plough was of steel, on the balance principle, and weighed 5 tons. A 6 horse-power agricultural engine, and an 8 horse-power traction engine with spring wheels, were then shown in action and gave great satisfaction.

After leaving the works, the visitors were conducted to the old Castle, the archæological features of which were fully described by Mr. Stephen Aveling, who showed himself intimately acquainted with every point. It may be mentioned that the people of Rochester have to thank the late Mr. Thos. Aveling for the admirable public garden and grounds surrounding the Castle, for to his initiative and untiring effort it was due that

what were formerly gardeners' plots were converted into the present form and dedicated for ever to the public. The visit was closed by the members and friends dining together at the well-known Bull Hotel, Rochester.

On Wednesday, the 13th July, a double visit was made; first to the Marine Engine Works of Messrs. Maudslay, Sons, & Field, Westminster Bridge Road, Lambeth; and afterwards to the works of the City and Southwark Subway, near London Bridge. At Messrs. Maudslay's renowned works were then being built the engines for the *Re Umberto*, of the Italian Navy, the engines of the *Spider* and *Grasshopper*, torpedo-catching steamers of the British Navy, and in a comparatively early stage those of the *Nile*, besides others of minor importance. The Italian engines claim the first place in point of power, having collectively a horse-power of 19,500, which will be capable of being worked up to 21,000. The total weight is limited to 1727 tons, which has necessitated the use of every means for combining lightness with strength, a result which has been attained by a free use of steel castings and minute attention to form. The engines are compound; the high-pressure cylinders being 47 inches and the low-pressure 90 inches in diameter, with 51 inches stroke. The valves are worked by a special arrangement of Joy's patent valve-gear, giving a sharp cut-off. The twin-propeller shafts are of Whitworth steel, 21½ inches in diameter, with a hole of 13 inches. Their length is 38 feet 6 inches.

In the engines of the *Spider* and *Grasshopper*, the combination of lightness with strength is even more fully carried out, these engines (of 3000 horse-power) being stated to be the lightest yet constructed in proportion to their power. The piston, slide, and connecting rods, as well as the crank shafts, are all hollow, and the framing and columns of steel throughout; the aggregate finished weight being only 28 tons. They are triple-expansion, and to run at 359 revolutions per minute, with a steam pressure of 150 lbs. It was difficult to believe that such small engines—they occupied a space of only 12 feet by 8 feet—could develop anything like such a horse-power.

The engines of the *Nile* are triple expansion, the cylinders being 43, 62, and 96 inches in diameter, with a stroke of 51 inches. The twin-propeller shafts are of Whitworth steel, 67 feet long, 16½ inches diameter, with a hole of 6½ inches. Some magnificent examples of modern tools were examined with great interest, especially a cylinder-boring machine standing 17 feet high, capable of boring up to 140 inches diameter by 12 feet deep; a planing and slotting machine

(vertical), capable of surfacing 25 feet by 20 feet, or slotting 20 feet in height, and a powerful screw-cutting machine 18 feet long, which cuts a 6-inch diameter thread in steel at a single cut. These large machines have each its own independent steam-engine.

On leaving Messrs. Maudslay's, the party proceeded to the Old Swan Pier to view the works in progress of the City and Southwark Subway. This work is remarkable for the originality and success not only of its permanent construction, but even more of the means used in the execution. The up and down lines are in separate tunnels, enabling the engineers to accommodate them to the difficult conditions met with at the City end. Under the river, for example, the tunnels run side by side, while, under the immediate approach on the north side, where land is so valuable, and the importance of avoiding existing buildings is so great, the one tunnel is made to run over the other, reducing the width of ground occupied to a minimum. Each tunnel is 10 feet diameter inside, formed of cast-iron rings bolted together in segments, each ring being 19 inches long. The mode of constructing the tunnels was equally simple and effective. An iron-lined shaft was sunk into the river bed from one side of the staging leading to the Old Swan Pier, and the first lengths of tunnel put in from it, north and south. Outside the 10-foot iron tunnel, and sliding over it as the cap of a telescope does, was a steel cylinder provided with a diaphragm, with a door in it strong enough to resist a rush of water in case of accident. Outside this were cutters, and a space in which the miners worked, and as the clay was cleared away in front, the shield was forced forward by a hydraulic press acting against the face of the ring last fixed of the tunnel, until there was space to insert another ring. The usual rate of progress was six rings, or 9 feet 6 inches of tunnel length, per diem. The space thus left outside the permanent cylinder was filled in and utilized as a means of effective protection to the iron by a very ingenious arrangement, specially designed by Mr. J. H. Greathead, the engineer to the subway. A grouting apparatus followed inside the tunnel the progress of the shield, and by means of compressed air (at about 30 lbs. per square inch) ejected lime or cement grouting, as might be required, through holes provided in the tunnel cylinder for the purpose. Commencing at the bottom the whole annular space was gradually filled up under pressure, and a complete coating of lime or cement secured round the whole of the ironwork.

At the time of the visit the two tunnels had been completed under the river and for some little distance beyond. Owing to

the confined space the visitors had to be divided up into several small parties, but every part of the operations was thoroughly seen, thanks to the untiring courtesy of Mr. Greathead and his assistants.

The third and last visit of the season was made on Wednesday the 19th October to Acton and Ealing, and was devoted to works of sewerage and water supply. Two of the former were visited, viz. the newly opened sewage works at Acton, and the older works at South Ealing. At Acton, where the party was received by Mr. W. Roebuck, C.E., the Chairman of the Local Board, and Mr. C. N. Lailey, the Engineer, the system of the International Sewage Purifying Company was seen in action for the first time in England on any large scale. The purification is effected by a combined process of precipitation and filtration. The precipitant used is magnetic ferrous carbon, mixed with compound sewage salts—sulphates of lime, calcium, and magnesia. These are gradually supplied to the sewage as it flows along a channel running on one side of the five precipitating tanks. After precipitation, the effluent is drawn off by a floating suction-pipe and passed through a filter-bed consisting of 4 inches of ordinary drain-pipes closely laid in shingle, 4 inches of fine gravel, 6 inches of sand, and 10 inches of magnetic spongy carbon, mixed with an equal quantity of sand and gravel. On this is a layer of sand 9 inches thick, and on top of all 1 inch of coarse magnetic spongy carbon. From the filtering bed the effluent passes away by an outfall drain to the Thames, and the sludge, which sinks by gravitation from the settling beds into a well, is pumped up into a tank, from whence it flows to the press room, where it is forced at a pressure of 60 lb. per square inch into filter-presses of an improved construction made by Messrs. Drake and Muirhead, of Maidstone. The duplex steam-pumping engines are by the same firm. No lime being used in the precipitant, it is expected that the sludge-cake will be valuable as manure.

The chief object of visiting the South Ealing works was to see in action the refuse-destructors which, while generally similar to Fryer's, have some distinctive points which Mr. C. Jones, the engineer to the Ealing Local Board, believes to have secured very satisfactory results. The chief of these is the introduction between the furnace proper and the chimney-shaft of a muffle furnace, or "fume cremator," by which means he claims to perfect the combustion and destroy all noxious fumes. The result of the burning is a clinker, well adapted and largely used for concrete work.

The last place visited was of a more agreeable character, and was the new reservoir being constructed by Messrs. Aird & Sons

at Hanger Hill, near Ealing, for the Grand Junction Water Company. Here the members and friends were received by Mr. Alexander Fraser, the Engineer to the Company, and Mr. B. P. Ellis, of the contracting firm. The reservoir is formed nearly on the top of a hill, and is 6½ acres water-surface area, with a maximum depth of 40 feet, the contents when full being about 52,000,000 gallons. The level of top water will be 193 feet 6 inches on Ordnance datum, and the reservoir will be used for the storage of filtered water to meet any unusual demand and provide against contingencies. The water will be pumped up from the Kew Bridge Station. The excavation amounted to 150,000 cubic yards, the whole of which has been used in the formation of the bank, which is 65 feet high on the north side, the ground at the south end being nearly at the level of top water. The excavation is in clay, and the bottom and internal slopes are puddled and punned and covered with 12 inches of cement concrete, the slopes being paved with Condy's vitrified bricks laid on edge in cement. The top of the internal slopes will be finished with a vertical wall 5 feet 6 inches high, coped with hollow terra-cotta blocks. It was stated that considerable trouble and expense had been caused by the discovery in excavating, at the upper end, of numerous pot-holes of gravel resting on sand and silt, which had necessitated a heavy wall of concrete to protect the public road and an adjoining reservoir from any earth slips. Alongside the reservoir, on its north-east side, is a filter, 65 feet internal diameter and 40 feet deep, formed with brickwork in cement, faced with vitrified brick, and coped in a similar manner to the reservoir.

After both this visit and that in July, the members and their friends met at dinner at the Guildhall Tavern, Gresham Street, City.

October 3rd, 1887.

HENRY ROBINSON, President, in the Chair.

STABILITY OF CHIMNEY SHAFTS.

By R. J. Hutton.

The author proposes in this paper to point out some errors which have crept into the theory of the stability of chimney shafts, and which have been repeated by writer after writer on the subject—and also to offer some considerations as to the economical application of the theory in practical designing. The errors in question occur in Rankine's 'Applied Mechanics,' and are repeated in Wilson's 'Boiler and Factory Chimneys,' Bancroft's 'Tall Chimney Construction,' and in a series of articles by Messrs. Molyneux and Wood on "the Design and Construction of Chimney Shafts" now appearing in 'Industries.' Besides these works, Mr. Campbell, in a paper read last year at the Royal Society of Victoria (Australia), on "the Stability of Structures as regards Wind Pressure," seems to consider it sufficient that the resultant should pass half-way between the inner and outer edges of the masonry, and advocates a structure of equal resistance, which would be unnecessary and uneconomical in the case of chimney shafts.

The first consideration in designing a shaft will be the draught required, and sometimes the height will be fixed irrespective of draught, with the object of carrying off noxious fumes. In either case these considerations will fix the height and the smallest area of the flue. These will be the main data. The more or less exposed situation of the site will determine the wind pressure to be allowed for, and local circumstances will decide the question of using heavy and expensive bricks, or local ones when such may be inferior in either weight or strength. Further, it will be desirable to use as small a batter as is consistent with stability and economy, in order to obtain an approximately uniform section of flue.

The form of horizontal section of chimney must of course be given. The round chimney will take the least amount of material and be the best form of flue; the octagonal will be very much the same as the round in these respects, will generally be considered more sightly, and will be more easily

built provided proper octagon corner bricks can be obtained. The square form will be most costly but most easily built, and may therefore sometimes be adopted with advantage where the only labour obtainable is comparatively unskilled.

The author proposes to treat of round, octagonal, and square shafts, with straight batters only. His conclusions will practically apply to curved batters, because the curvature is generally very slight. Curvature diminishes the surface exposed to the wind, but at the same time diminishes in a greater ratio the counteracting weight. It is therefore no gain as regards economy. It adds to the appearance, and at the same time somewhat to the difficulty of construction. In brickwork, unless the curvature is very slight, the necessary use of uneven beds of mortar, to give the summering, will bring an unfair proportion of pressure on the outer edge, which is in any case the most severely strained. This the author regards as a grave defect.

The word diameter when not qualified will be used to mean the shortest diameter.

Fig. 2 (page 7) shows the two forces acting on the structure, viz. P the resultant pressure of the wind on the exposed side, and W the weight of the masonry. The word masonry will be taken in this paper to include brickwork.

The sufficient conditions of stability are, that the resultant of these two forces above any horizontal section shall cut that section so far within the outside edge as to cause

I. No compressive stress greater than the material can safely bear.

II. No tensile stress at all.

The necessity of the first condition is self-evident.

The necessity of the second condition is not at once so evident. It might be argued that the chimney would not necessarily be injured by the windward joints momentarily opening during some exceptionally severe gust, so long as this opening did not bring a destructive stress on the leeward joints. The answer is, that although it is possible that such opening might occur without apparently or even really injuring the shaft, yet there would be great danger of the shaft being demoralised in such a case, and that in fact appearances tend to show that some such action as splitting vertically and breaking bond in the portion over the opening does take place.

The tenacity of mortar cannot be relied on, more especially in a chimney where it is exposed to heat.

Various devices are tried, such as mixing salt with the

mortar, probably to act as a flux, and iron scale to make it set quickly,* but it is now generally admitted that however wise it may be to adopt every method of making the mortar as strong and tenacious as possible, it would be in the highest degree imprudent to count upon it for the stability of a structure. In many cases chimneys have been cut, to correct settlements, &c., and this of course destroys all tenacity along the line of the cut.

The force W (weight of masonry) will act along the vertical axis of the shaft, and will equal the cubic contents of the masonry multiplied by the coefficient δ, the density, or weight of a unit of volume. δ is usually expressed in lbs. per cubic foot.

To get an expression for the volume it will be assumed that the chimney is built with a straight internal batter instead of in steps. If the steps are at equal heights this assumption will be almost mathematically correct. If the heights are uneven, it will be possible to make a very close approximation, by taking the thickness of masonry at the top of such a dimension that it and the thickness at the base will average the area of section of masonry.

If δ = density of masonry,
T = thickness of masonry at top,
R = outside semidiameter at top,
t = thickness of masonry at any section X X,
r = outside semidiameter at any section X X,
y = depth of section X X from top,
$\frac{1}{\beta}$ = outside batter, so that $r = \mathrm{R} + \frac{y}{\beta}$,

Then

$$\mathrm{W} = \frac{\pi \delta y}{6} [\,(2r - t)(2t + \mathrm{T}) + (2\mathrm{R} - \mathrm{T})(2\mathrm{T} + t)\,]$$

for a circular section.

For square sections π must be replaced by 4, and for octagonal sections by $8(\sqrt{2}-1) = 3{\cdot}3136$.

The force P, viz. the total pressure of the wind on the exposed surface of the shaft is more difficult to arrive at with precision. See Fig. 1.

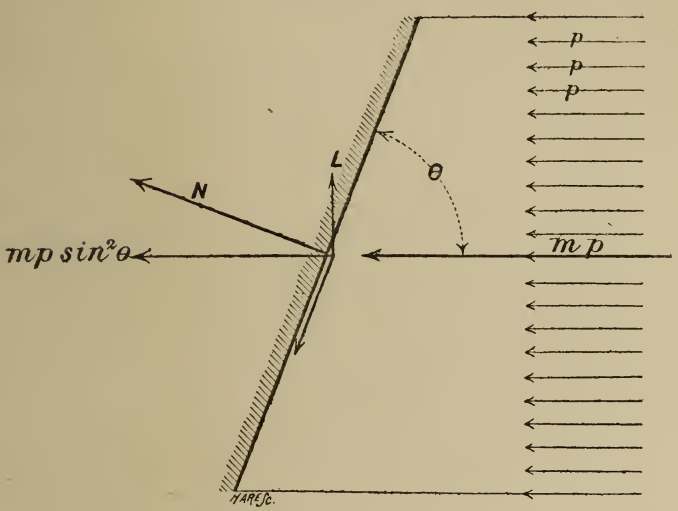
If p = the pressure per unit of area which the wind would exert on a plane surface square to its direction,
l = the length of a rectangular plane surface of height unity, the length l of which is inclined to the direction of the wind, while the height unity is perpendicular to it,

* Bancroft, 'Tall Chimney Construction.'

θ = the angle of inclination of l to the wind,
m = the projection of l parallel to the direction of the wind, so that $m = l \sin \theta$.

Then mp is the force acting on the inclined surface.

FIG. 1.



Let N = the component of this force normal to the inclined surface. The component along the surface has no effect; and $N = mp \sin \theta$ may be resolved into a lateral force $L = N \cos \theta = mp \sin \theta \cos \theta = lp \sin^2 \theta \cos \theta$, perpendicular to the direction of the wind, and a direct force $= N \sin \theta = mp \sin^2 \theta = lp \sin^3 \theta$, parallel to the direction of the wind.

In the case of a cylinder we may suppose the circumference of the cylinder to be made up of innumerable little lengths l, the sides of an equiangular polygon. If these lengths are sufficiently small to make the polygon approximate to a circle, it is evident the lateral components L will balance each other, and the total pressure on a semicircle of height unity will equal $p \Sigma l \sin^3 \theta$ which means the sum of a number of equal divisions of the circumference multiplied by the cubes of the sines of the angles of their middle points, taken all round the semicircumference. In the language of the calculus this is $p \int_0^{\pi} \sin^3 \theta \, ds$

$= p\,r \int_0^{\pi} \sin^3\theta\, d\,\theta = \frac{4\,p\,r}{3} = \frac{2}{3}$ of the pressure which the wind would exert on the diametral section.

We see then that the effect of wind on surfaces of different form is equal to its effect on the projection of the same surface square to the direction of the wind multiplied by a coefficient which will vary with different forms of surface, and that in general if A = area of projection and μ = coefficient, then $P = \mu p A$.

We shall take P and μ to refer to the case where the wind is perpendicular to the diameter of the horizontal section of the shaft, and $P_\theta\ \mu_\theta$ to mean the same when the wind is inclined to the diameter at an angle θ (measured in a horizontal plane). In the case of a circle as shown above, $\mu = \frac{2}{3}$; in that of a square $\mu = 1$; and in that of an octagon $\mu = \frac{1}{\sqrt{2}} = \cdot 7071$.

The author would not have dwelt so long on this matter but that a different coefficient for a circle has been adopted by Rankine from experiment; and the writers mentioned above have not only adopted it, but have followed Mr. Wilson in attempting to show that it accords with theory. Mr. Wilson falls into the error of treating the wind pressure as if it were applied uniformly over the surface, instead of over the projection of the surface on a plane square to the direction of the wind. This ought to have led him to a coefficient of 0·78, but he makes the further mistake of taking the square of the average of a number of coefficients, instead of the average of their squares.

Experiments, such as we have, agree pretty well with this value of μ for a circle, and with the coefficients for inclined surfaces. Hutton and Vince's experiments, as quoted by Mr. Bender in his recent paper on "Structures to Resist Wind," read at a meeting of the Inst. of Civil Engineers, give the following coefficients for surfaces inclined to the wind:—

Angle of inclination	90	70	50	30	10
Coefficient according to experiment ..	1·00	·90	·69	·33	·05
„ „ „ theory	1·00	·90	·59	·25	·03

The author using Bresse's empirical formula, which is based on these experiments, and applying it to a polygon of 36 sides, a close approximation to a circle, gets a coefficient of 0·74. Borda gets a coefficient of 0·57 for small cylinders. Hutton and Vince therefore get coefficients higher than theory, and Borda lower than theory; but experiments on very small surfaces are known, within certain limits, to give too low results,

and Borda gives the following table showing the effect of increased surfaces on the intensities of pressure registered:—

Surface ..	9	16	36	81	sq. inches.
Intensities	100	109	119	129	..

This shows a difference of intensity of nearly 20 per cent. between experiments on surfaces of 3 inches square and 6 inches square, and a further increase of 8 per cent. when the surface is increased to 9 inches square.

The difference between the coefficient 0·74 derived by applying the results of Hutton's experiments to the case of cylinders, and the coefficient 0·57 found directly by Borda's experiments on small cylinders, is 26 per cent. of the mean, and the theoretical coefficient lies between the two. The author has not been able to ascertain the relative sizes of the plates used in Hutton's and Borda's experiments, but Borda's cylinders were small, and Professor Unwin says that his experiments on plane boards 2 feet square at different inclinations to the wind, agreed almost exactly with Hutton's, so that Hutton's plates were probably about that size.

The difference of size of the plates experimented on might account for a great part of the discrepancy, and the rest may be due to the fact that the vacuum formed behind the plates would be greater than that behind the cylinder, which acts with air as the stern of a ship does with water.

The author is aware that the experiments of Mr. Baker at the Forth Bridge show a great decrease of pressure when the surfaces experimented on attain a size comparable with the surface of a chimney shaft. That does not affect the present question, viz. that of comparing the effect of wind on cylinders with that on plane surfaces.

The conclusion the author comes to on this point is, that inasmuch as results of experiments give coefficients of ·57 and ·74, whereas theory gives ·67, this latter may be looked upon as a fair average value, if indeed the higher coefficient ·74 should not be adopted as being on the safe side. Nevertheless the coefficient universally adopted in practice and sanctioned by Rankine, probably on account of Borda's experiments, is ·50. This is nearly as much lower than Borda's coefficient as Borda's is lower than the theoretical, and seems to the author unwarrantably far on the unsafe side.

The author considers that the law of the squares of the sines agrees sufficiently with experiments to warrant him in adopting it, for the purposes of comparison between different forms of shafts, effects of different directions of the wind, &c. It may seem that in the absence of any reliable data as to the

FIG. 2.

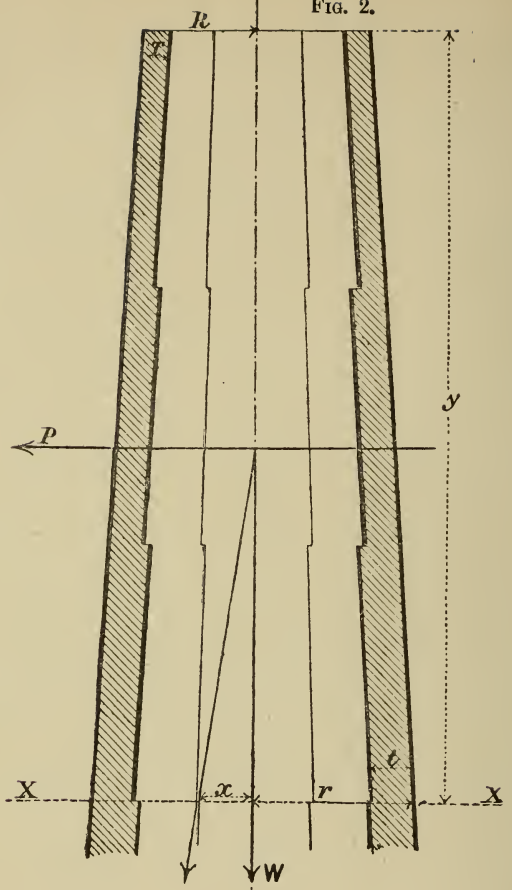
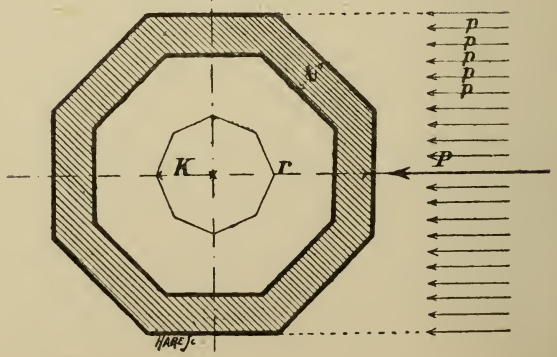


FIG. 3.



pressure of the wind in the most simple cases, it is absurd to refine so much; but very probably the best data we shall get on this important subject of wind pressure, will be by comparing the failure of just such structures as tall shafts, and to compare such failures we must have a sound basis to work upon.

The force P of the wind has been taken to act horizontally because that will give the maximum effect. Its action would in reality be normal to the batter, but the batter of chimney shafts is so small that the difference would be inappreciable.

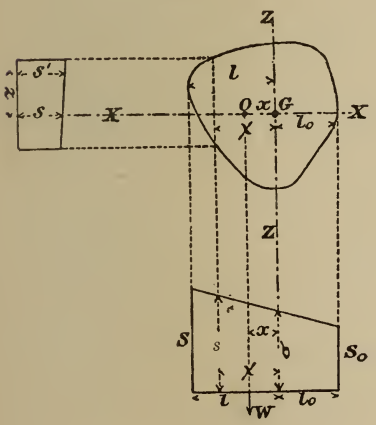
Referring to Fig. 1, by taking moments we have

$$x\,\mathrm{W} = p\,\mathrm{M},$$

where M = moment of P round the point x with pressure unity.

Now if the external dimensions are fixed so that M does not vary, W will be a minimum (i. e. the least material will be required, and therefore the least cost incurred) when x is as large as possible. But x is limited by the conditions I. and II. To satisfy condition II., x must not be greater than a certain length K from the centre of the shaft.* K is the semidiameter

Fig. 4.



* If a force W acts perpendicularly to a plane section of any shape, not through the centre of gravity of its area, it will produce different stresses at different points of the surface.

The hypothesis universally adopted, usually known as the "law of the trapesium," or "Navier's law," amounts to assuming that the plane surface after deformation according to the law of elasticity will still be a plane.

Let the point G, Fig. 4, be the centre of gravity of the surface, and let the force W act through the point O, at a distance x from G.

The weight W will be balanced by elementary stresses s' acting on elements of area $d\,\Omega$. Since the deformed surface is still a plane, the stress s' in the stress diagram for any cross section parallel to ZZ will be of the form $s + \beta z$, where s = stress in the same cross section in the line X X.

For the same reason s will be of the form $\sigma + \alpha\chi$, where σ = the stress at the centre of gravity of the area.

$$\therefore\ s' = \sigma + \alpha\chi + \beta z.$$

of the "kernel" of the section. The kernel of the octagon is shown on Figs. 2 and 3. So long as the resultant cuts the section within the kernel there is no tension.

But, from the conditions of equilibrium,

$$\int s' d\Omega = W$$

$$\int \chi s' d\Omega = x W$$

$$\int z s' d\Omega = 0.$$

Substituting $\sigma + \alpha\chi + \beta z$ for s' and remembering that $\int \chi d\Omega = 0$, and $\int z d\Omega = 0$, because the axes pass through the centre of gravity, we have

$$W = \sigma\Omega$$

$$x W = \alpha \int \chi^2 d\Omega + \beta \int \chi z d\Omega$$

$$0 = \beta \int z^2 d\Omega + \alpha \int \chi z d\Omega.$$

Now it is evident from inspection of the square, octagon, and circle, that the moment of inertia round any axis X passing through the centre of gravity, will be identical with that round an axis Y, perpendicular to X, passing also through the centre of gravity.

But if ρ be the distance of any element of area $d\Omega$ from the centre of gravity, we have

$$\int \rho^2 d\Omega = \int X^2 d\Omega + \int Y^2 d\Omega = 2I;$$

$$\therefore \quad I = \int \frac{\rho^2 d\Omega}{2} = \text{constant}.$$

Now if θ = the angle that any axis Y Y makes with Z Z, Fig 5, we have

$$I = \int Y^2 d\Omega = \int (z \sin\theta - \chi \cos\theta)^2 d\Omega$$

$$= I - 2 \sin\theta \cos\theta \int \chi z d\Omega$$

or $\int \chi z d\Omega = 0$ for the forms of section under consideration;

$$\therefore \quad W = \sigma\Omega$$
$$x W = \alpha I$$
$$\beta = 0.$$

But

$$s' = s + \beta z = s,$$

which means that the stresses are uniform along any line perpendicular to X X; also

$$s = \sigma + \alpha\chi.$$

When $\chi = +r$, s = stress at leeward edge = S,

$$S = \sigma + \alpha r;$$

when $\chi = -r$, s = stress at windward edge = S_0,

$$S_0 = \sigma - \alpha r;$$

$$\therefore \quad \alpha = \frac{S - \sigma}{r} = \frac{\sigma - S_0}{r}.$$

But

$$K \text{ (see note)} = \frac{r-t}{2} + \frac{t^2}{4r} \text{ for a circle,}$$

$$= \frac{2(r-t)}{3} + \frac{t^2}{3r} \text{ for a square,}$$

$$= \frac{3-\sqrt{2}}{3}\left(r - t + \frac{t^2}{2r}\right)$$

or

$$0{\cdot}53\,(r-t) + 0{\cdot}26\,\frac{t^2}{r} \text{ for an octagon.}$$

We may in general neglect the last term containing t^2, making K for a circle $= \frac{r-t}{2}$. The values of $\frac{r-t}{2}$ for different proportions of r and t are shown in the diagram Fig. 5,

---

But $$\alpha = \frac{x\,W}{I} \text{ and } \sigma = \frac{W}{\Omega}$$

$$\therefore\ S = \frac{W}{\Omega}\left(1 + \frac{r\,\Omega\,x}{I}\right)$$

$$S_0 = \frac{W}{\Omega}\left(1 - \frac{r\,\Omega\,x}{I}\right).$$

When the limit of no tension in the windward edge is reached, $S_0 = 0$ or $x = \frac{I}{r\,\Omega}$.

Calling this value of x "K," we have

$$K = \frac{I}{r\,\Omega},$$

where K = the semidiameter in the direction X X of the "kernel" of the section.

Hence $$S = \frac{W}{\Omega}\left(1 + \frac{x}{K}\right)$$

$$S_0 = \frac{W}{\Omega}\left(1 - \frac{x}{K}\right)$$

It is easily found that for a hollow figure of semidiameter r and thickness t, of circular section,

$$I = \frac{\pi}{4}\left(r^4 - (r-t)^4\right), \quad \Omega = \pi\left(r^2 - (r-t)^2\right), \quad K = \frac{r^2 + (r-t)^2}{4r};$$

of octagonal section,

$$I = \frac{4(\sqrt{2}-1)(3-\sqrt{2})}{3}\left(r^4 - (r-t)^4\right), \ \Omega = 8(\sqrt{2}-1)\left(r^2 - (r-t)^2\right)$$

$$K = \frac{3-\sqrt{2}}{6r}\left(r^2 + (r-t)^2\right);$$

of square section,

$$I = \frac{4}{3}\left(r^4 - (r-t)^4\right) \quad \Omega = 4\left(r^2 - (r-t)^2\right) \quad K = \frac{1}{3r}\left(r^2 + (r-t)^2\right)$$

FIG. 5.

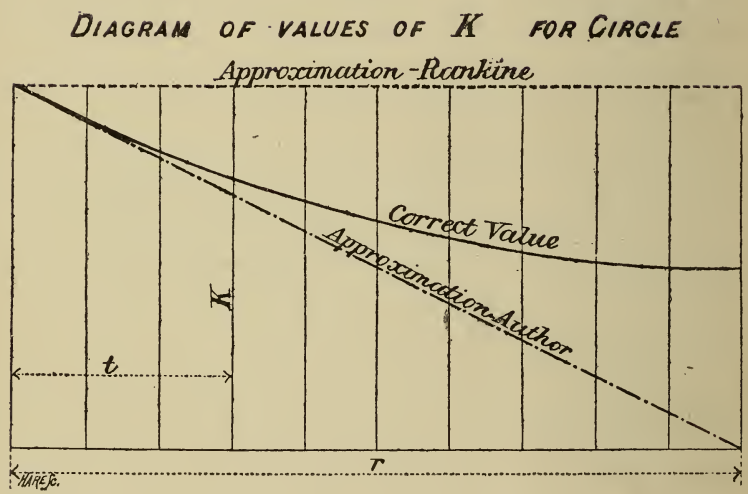


DIAGRAM OF VALUES OF K FOR CIRCLE
Approximation - Rankine
Correct Value
Approximation Author
K
t
r

together with the exact values of K. It is evident that $\frac{r-t}{2}$ is a very close approximation to K in the cases which most frequently occur in practice, viz. when t does not exceed one-third of K, and that in all cases the difference is on the safe side.

Rankine gives the same formula as above, but adds that as t is generally very small as compared with the semidiameter it may be assumed = 0, and hence he gets for a circle $K = \frac{r}{2}$.

The values of $\frac{r}{2}$ are shown in the diagram Fig. 5. They are not as close an approximation as the $\frac{r-t}{2}$, even when t is very small, and in all cases they are on the unsafe side.

The following table gives some notable instances of the relative proportions of t and r, and shows that t is far from being negligible as regards r.

	Height.		r		t	
	′	″	′	″	′	″
St. Rollox	435	6	20	0	2	7½
Townsend's	454	0	16	0	5	7½
Mechernich	397	3	12	4	6	7
West Cumberland	248	0	12	9	1	10½

In the case of the Mechernich shaft the values of K are:—

Rankine's approximation	6·15
Correct value	3·74
Author's approximation	2·86

The author's approximation in this case is not very close, but it is only given for comparison. It is an extreme case owing to the unusual proportionate thickness of the masonry, and is beyond the limits of correction mentioned above.

In the more ordinary case of Townsend's shaft the values are:—

Rankine	8·00
Correct	5·70
Author	5·20

In the very favourable case of St. Rollox, designed by Rankine, the values are :—

Rankine	10·00
Correct	8·77
Author	8·69

Since p varies directly as K, these figures show that Rankine's approximation in cases of actual practice gives a value for p, the safe wind pressure, greater than the correct one by a ratio varying from 14 per cent. in the St. Rollox to 64 per cent. in the Mechernich. If we also take into account the ratio due to the difference of the coefficients $\frac{1}{2}$ and $\frac{2}{3}$ we find the errors to vary from 52 per cent. to 120 per cent. of the correct value.

The Mechernich shaft was designed to withstand a wind of 160 lbs. per square foot. According to Rankine it would stand 70 lbs., according to the author 32 lbs. In such an extreme case the author does not use any approximation, but calculates the exact value of K, and without doubt so would Rankine himself have done; but he states in his book that the approximation is sufficiently near, without any qualification, and it has been, as might be expected, copied and quoted on his authority. The above three estimates of wind pressure which would be sufficient to damage the Mechernich shaft (an actually existing one) show clearly the confusion there is at present on the subject, and the necessity of some clear theoretical basis before any real comparison of results can be obtained.

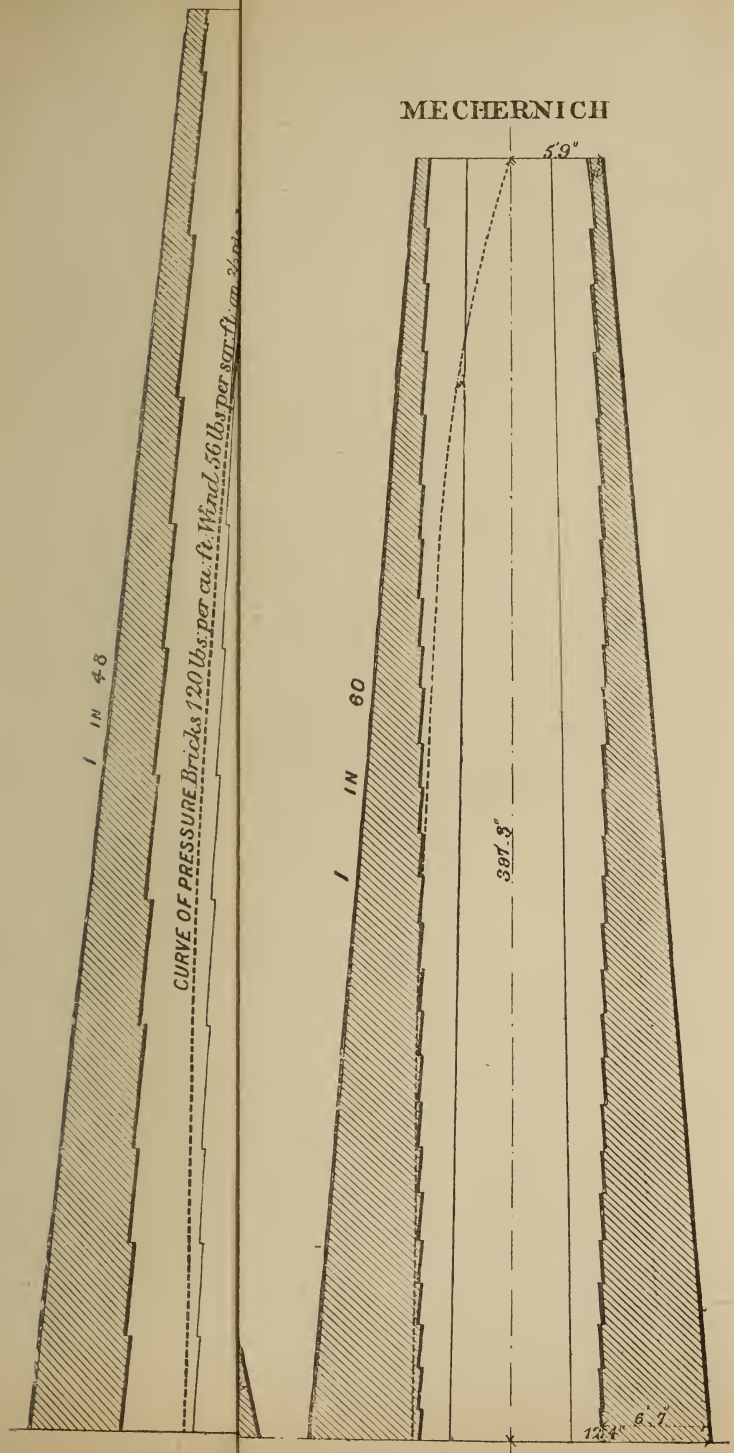
The designer of the Mechernich shaft has evidently followed a very old method, viz. that of taking moments round the leeward edge of the section. This amounts to supposing that the material will stand an infinite crushing stress, so that the shaft will be all right so long as it is not just about to tumble over its leeward edge. To make up for this the designer has allowed for an enormous wind pressure. The author submits that that is a very crude way of treating the subject.

Thus we have values of K and the coefficient μ for the various forms of shaft when the direction of the wind is square to a diameter. For the circle, μ will not vary with the direction of the wind; for the square and octagon it will vary.

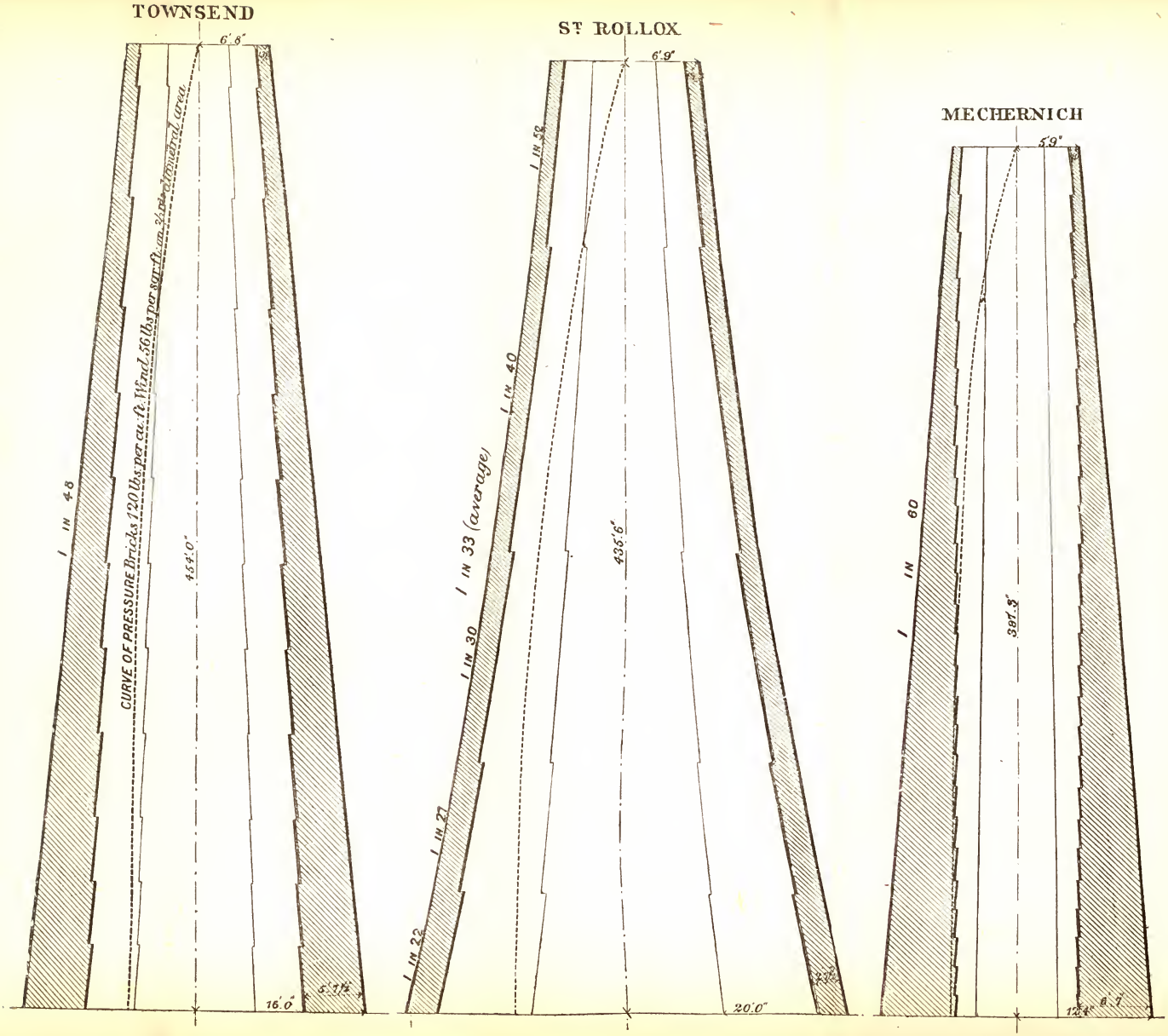
Since I is constant for any axis through the centre of gravity in the forms of section under consideration,

TO

MECHERNICH



To face p. 162.


TOWNSEND
6'.8"
1 IN 48
CURVE OF PRESSURE Bricks 120 lbs per cu. ft. Wind 56 lbs per sq. ft. on 2/3 rd of Diametral area
454'.0"
16'.0"
5'.7½"
ST ROLLOX
6'.9"
1 IN 52
1 IN 40
1 IN 33 (average)
1 IN 30
1 IN 27
1 IN 22
435'.6"
20'.0"
MECHERNICH
5'.9"
1 IN 60
387'.3"
12'.4"
6'.7"

To face p. 162.

If K_θ, r_θ be the lengths for an axis inclined at an angle θ to the diameter corresponding to K and r,

$$K_\theta r_\theta = \frac{I}{\Omega} = \text{constant};$$

therefore the boundary of the kernel, which is the locus of the extremity of K, is evidently a series of right lines at right angles to the diagonals, forming a figure similar to the figure

Fig. 6.

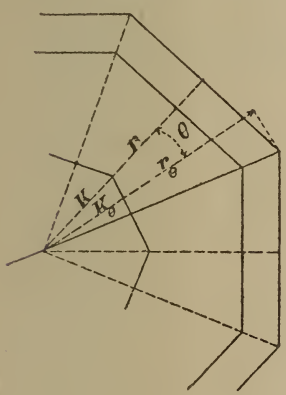
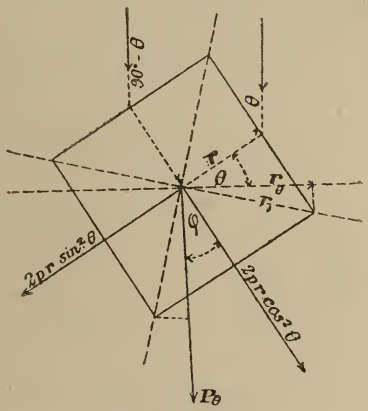


Fig. 7.



of the section, but with the diameters of one lying on the diagonals of the other. (See Fig. 6.)

This applies to all figures of which the moment of inertia is constant for different axes, i. e. all equiangular and equilateral polygons the number of whose sides is a multiple of four, but it does not apply to a hexagon.

To find the direction of the wind most unfavourable to stability, and the allowance to be made in consequence, it will suffice to find the wind pressure p_θ which, acting along a diameter, would require a weight of masonry sufficient to balance a wind pressure p inclined at an angle θ to the diameter.

In a square (Fig. 7), this pressure will produce normal forces on each exposed side of the square equal to $2\,p\,r\,\sin^2\theta$ and $2\,p\,r\,\cos^2\theta$ respectively. They will act through the centre, and their resultant P_θ will make an angle ϕ with a diameter, so that

$$P_\theta = 2\,p\,r\,\frac{\sin^2\theta}{\sin\phi} = 2\,p\,r\,\frac{\cos^2\theta}{\cos\phi}$$

Thus we have

$$\mathrm{K\,W} = 2\,p_\theta\,r \times \frac{y^2}{3} \times \frac{r + 2\,\mathrm{R}}{2\,r}$$

$$\mathrm{K}_\phi\,\mathrm{W} = 2\,p\,r\,\frac{\cos^2\theta}{\cos\phi} \times \frac{y^2}{3} \times \frac{r_\theta + 2\,\mathrm{R}_\theta}{2\,r_\theta}$$

but

$$\frac{r_\theta + 2\,\mathrm{R}_\theta}{2\,r_\theta} = \frac{r + 2\,\mathrm{R}}{2\,r}$$

and

$$\mathrm{K}_\phi = \frac{\mathrm{K}\,r}{r_\phi} = \frac{\mathrm{K}\,r}{r_1 \cos(45^\circ - \phi)} = \frac{\mathrm{K}}{\sqrt{2}\cos(45^\circ - \phi)}$$

$$= \frac{\mathrm{K}}{\cos\phi + \sin\phi}$$

$$\frac{p_\theta}{p} = \frac{\cos^2\theta\,(\cos\phi + \sin\phi)}{\cos\phi}$$

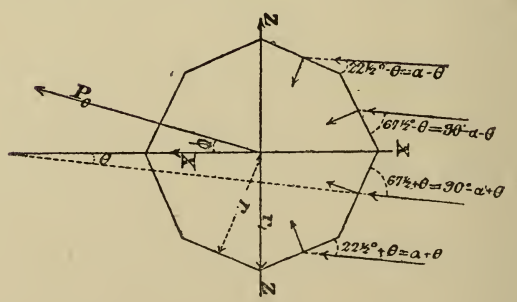
Now

$$\frac{\sin^2\theta}{\sin\phi} = \frac{\cos^2\theta}{\cos\phi}$$

$$\frac{\cos\phi + \sin\phi}{\cos\phi} = \frac{\cos^2\theta + \sin^2\theta}{\cos^2\theta} = \frac{1}{\cos^2\theta}$$

$$\therefore\quad p_\theta = p = \text{constant.}$$

Fig. 8.



In an octagon (Fig. 8), resolve the normal forces perpendicular to and along the axis X X.

Then, calling $22\frac{1}{2}° = a$, we have

$$Z = p\,l\Big(\sin^2(a+\theta)\cos a + \cos^2(a-\theta)\sin a - \cos^2(a+\theta)\sin a - \sin^2(a-\theta)\cos a\Big)$$

$$= p\,l\,(\cos a + \sin a)\sin 2a \sin 2\theta$$

$$= p\,l\cos a \sin 2\theta$$

$$X = p\,l\Big[\sin^2(a+\theta)\sin a + \cos^2(a-\theta)\cos a + \cos^2(a+\theta)\cos a + \sin^2(a-\theta)\sin a\Big]$$

$$X = p\,l\,(\cos a + \sin a)\Big(1 + \cos 2\theta\,(1 - \sin 2a)\Big)$$

$$= p\,l\sqrt{2}\cos a\Big(1 + \cos 2\theta\,(1 - \sin 2a)\Big)$$

$$P_\theta = \frac{X}{\cos\phi}$$

$$K\,W = 2\,\mu\,p_\theta\,r\frac{y^2}{3} \times \frac{r + 2R}{r}$$

$$K_\phi\,W = P_\theta \times \frac{y^2}{3} \times \frac{r_\theta + 2R_\theta}{r_\theta}$$

$$2\,\mu\,p_\theta\,r = \frac{K}{K_\phi}P_\theta = \frac{r_\phi}{r} \times \frac{X}{\cos\phi} = \frac{X}{\cos a},$$

$$\Big(\text{since } r_\phi = r_1\cos\phi = \frac{r}{\cos a}\cos\phi\Big)$$

$$p_\theta = \frac{X}{2\,\mu\,r\cos a}$$

$\therefore$ when

$$p_\theta = \text{max.},\quad X = \text{max.}$$

$$\text{but } X = p\,l\sqrt{2}\cos a\Big(1 + \cos\,2\,\theta\,(1 - \sin\,2\,a)\Big)$$

which is evidently a max. when $\cos 2\theta = 1$ or $\theta = 0$, i. e. when the direction of the wind is along a diagonal, in which case

$$X = pl\sqrt{2}\cos a\Big(2 - \frac{1}{\sqrt{2}}\Big)$$

$$\frac{X}{\cos a} = p\,l\,(2\sqrt{2} - 1)$$

and

$$p_{\max.} = \frac{p\,l\,(2\sqrt{2}-1)}{2\,\mu\,\mathrm{R}} = p \times \sqrt{2}(\sqrt{2}-1)(2\sqrt{2}-1)$$

$$\mu\,p_{\max.} = \frac{p\,l\,(2\sqrt{2}-1)}{2\,\mathrm{R}} = p \times (\sqrt{2}-1) \times (2\sqrt{2}-1)$$

$$= p\,(5 - 3\sqrt{2}) = 0{\cdot}7574\,p$$

Therefore in an octagon the worst direction of the wind will be along a diagonal, and it can be provided for by taking a coefficient of (say) ·75 instead of $\frac{1}{\sqrt{2}}$.

We may take the coefficients then to be

For a square	1·00
For a circle	·67
For an octagon	·75

If we were to apply Hutton's coefficients these figures would become

For a square	1·27	wind in direction of diagonal
For a circle	0·74	„ „
For an octagon	0·85	„ „

Returning to the equation

$$\mathrm{KW} = p\,\mathrm{M},$$

it is evident that when outside dimensions are fixed, M is invariable, and W therefore varies inversely as K. ∴ when W = minimum, K = maximum. But $\mathrm{K} = \frac{r-t}{2}$ very nearly. ∴ when K = maximum, t = minimum. In other words, to make W as small as possible t must be as small as possible. As it cannot be less than the thickness at top it must equal it, or the masonry must be of uniform thickness.

In small shafts it is possible to make the thickness uniform throughout without reducing the base to such an extent as to cause too great extreme pressure there. In large shafts, condition (I.) will come into play.

If Ω = area of horizontal section, S = highest admissible stress on the masonry of leeward edge (see note, page 8).

$$\mathrm{S} = \frac{\mathrm{W}}{\Omega}\left(1 + \frac{x}{\mathrm{K}}\right).$$

If S_0 = stress on masonry at windward edge,

$$S_0 = \frac{W}{\Omega}\left(1 - \frac{x}{K}\right),$$

and if this becomes negative, S_0 will be the extreme tension on the section.

When S reaches the limiting value, the bottom thickness must be increased, but it will still be economical to keep it as small as will suffice to give the requisite value of W together with sufficient area of base, that is, t must be such that the resultant may cut the edge of the kernel, and at the same time the extreme pressure may = S.

In that case

$$S = \frac{2W}{\Omega}, \text{ and } KW = p\mu\frac{y^2}{3}(r + 2R)$$

$$KS\Omega = 2\mu p\frac{y^2}{3}(r + 2R)$$

$$t\left(r - t + \frac{t^2}{2r}\right)(2r - t) = \frac{4\mu p y^2}{3\pi S}(r + 2R).$$

This may be read,

$$\frac{p}{S} = \frac{3\pi}{4\mu y^2(r + 2R)}\, t\,(2r - t)\left(r - t + \frac{t^2}{2r}\right)$$

If r is fixed, p is a maximum when $t = \frac{r}{2}$. That is, for each value of the batter there is a ratio of p to S which cannot be passed.

The following table gives the values of $\frac{p}{S}$ for different batters in the case of a shaft 480 feet high, with 8 feet external radius at top, p in lbs. per square foot, and S in tons per square foot.

Batters—plumb,	1 in 120,	1 in 60,	1 in 48,	1 in 40,	1 in 36,	1 in 30,	1 in 24,	1 in 20.
Values of $\frac{p}{S}$ —	0·31,	0·90,	1·86,	2·49,	3·22,	3·77,	5·01,	7·23, 9·90.

This shows for instance that, if S were taken at 20 tons per square foot, it would be impossible to design such a chimney with a batter of 1 in 48 to resist more than 50 lbs. per square foot wind pressure.

It may be that the only dimension fixed besides the height is the inside diameter at top, which fixes the area of the flue.

This would leave the batter (which implies the bottom diameter) to be fixed.

In this case, the greater the batter, the less the value of W.

The following table shows that, as the batter decreases, the weight of masonry increases, and that a certain rate of batter is reached beyond which it is impossible to satisfy the conditions of stability, however much the thickness of masonry may be increased. It shows, too, that the greater the thickness of masonry at top, the steeper the limiting batter becomes, assuming an even inside batter.

Height = 360 feet. Internal semidiameter at top 5 feet.
δ = 112 lbs. per cubic foot.
p = 55 lbs. per square foot.
Chimney circular.

Straight Internal Batter.

Batter.	Thickness at top = 1.		Thickness at top = 2.	
	S in tons per sq. ft.	W in tons.	S in tons per sq. ft.	W in tons.
1 in 24	17·8	2521	..	..
1 in 30	17·0	2916	24·2	2763
1 in 36	16·5	3851	21·4	3130
1 in 40	..	..	20·1	3545
1 in 43	..	..	19·0	4418
1 in 40	..	..	17·9	5618
1 in 36	16·2	4678	..	..

It might be supposed that by increasing the batter, and thus exposing more surface to the pressure of the wind, more masonry would be required to resist it. This idea has perhaps led to the adoption of steep batters. Perhaps, as is evidently the case in the Mechernich chimney, their object is to provide a better flue. The table shows that the additional wind pressure is more than compensated by the greater stability of a broad base.

The St. Rollox chimney shows that Rankine was aware of the advantage of a good batter.

The weight of the masonry, and safe compressive stress per super foot to be assumed, are very important items in designing a shaft. Rankine gives 112 lbs. per cubic foot for the usual weight of brickwork, but adopts himself, for the St. Rollox chimney, a weight of 121 lbs. per cubic foot. The bricks should be weighed in each separate case, and care should be taken that

they are dry when weighed. They will easily absorb 15 per cent. to 20 per cent. of their weight of moisture, but in a shaft exposed to heat they would probably lose this again. Bricks vary a good deal in weight, but the author believes that good machine-made bricks (not fire-bricks) would seldom weigh more than 105 lbs. per cubic foot when dry. It seems to the author that in this respect also, designers have leant somewhat to the unsafe side, fortunately an unusual thing in engineering practice.

It should be noted that too high a value of weight of bricks gives unsafe results as regards condition (II.) (no tension), while as to condition (I.) (safe compressive stress) too low a value would be unsafe, but this can be allowed for in the value assumed for the extreme stress.

"S," the extreme stress, is sometimes taken, in the case of chimneys, as high as 19 tons per square foot for brickwork in lime mortar, where the lime is very liable to injury from the heat. Now in cases of large dams of rubble masonry in cement, S is never taken higher than 10 tons per square foot, but this is supposed to leave a factor of safety of 10. The author questions whether in many cases of bricks in mortar 19 tons per square foot would leave a factor of safety of more than 3 or 4.

It is not so easy as may at first appear to derive conclusive information from the failure of shafts, though their lessons of course should not be neglected. The tensile force of the mortar would have to be taken into account, if the curve of pressure were supposed to have passed outside the limit of stability, because the compressive stress "S" exerted at the leeward edge in that case is very much greater than the value given by the formula $S = \frac{W}{\Omega}\left(1 + \frac{x}{K}\right)$, when once the windward edge has opened. Shafts are, or ought to be, expressly designed to prevent any such opening, because of the ultimate damage it would do the shaft; but the edge might possibly open to a considerable extent before the chimney failed. Allowance would have to be made for the extent the shaft bent out of the perpendicular before failing. The top of Townsend's chimney was 7 feet 9 inches out of plumb before it was straightened by cutting.*

The author does not suppose that because of the remarks he has made the chimneys concerned will immediately set about to tumble down. The conclusion he arrives at is that the wind pressure of 56 lbs. per square foot, which is generally taken as the maximum to be provided against, is so much in excess of the mean pressure on the large surface of a chimney shaft, that

* Bancroft, 'Tall Chimney Construction.'

it serves as a sufficient factor of safety, even when reduced from foregoing considerations. It must be remembered, however, that as regards condition (II.) (no tension) it is the only factor of safety employed.

It is a much smaller factor for tall shafts than for lower ones, because the pressure increases with altitude.

Experiments seem to prove that the pressure of the wind increases in a nearly even ratio, so that

$$\frac{p_{\mathrm{H}}}{p_h} = \frac{\mathrm{H} + d}{h + d},$$

where p_{H}, p_h are the pressures at the heights H and h respectively, measured from the ground, and "d" is a depth below ground which Mr. Stevenson fixes at 72 feet.

In this case if p_0 be the pressure at ground level, and h = total height of chimney,

$$p_y = \Big((h - y) + d \Big) \times \frac{p_0}{d}$$

$$p_h = (h + d)\frac{p_0}{d}$$

and the moment of the wind force is changed from

$$\mu p \frac{y^2}{3} (r + 2\,\mathrm{R})$$

into

$$\frac{\mu p_0 y^2}{6\,d} \Big[(2\,h + 2\,d - y)\, r + (4\,h + 4\,d - y)\, \mathrm{R} \Big].$$

The author suggests that observations should be made to fix p_0 and d with practical accuracy. At such a height as 450 feet the pressures are not only higher but probably far more uniform and therefore more dangerous.

The author regrets that want of time has prevented his going more fully into the subject-matter of this paper.

He has to express his thanks to Mr. W. B. Coventry for help in working up the subject, and his indebtedness to Messrs. Bancroft's valuable work on 'Tall Chimney Construction,' and to a paper on the Mechernich chimney by Mr. J. M. Wood, in the Transactions of the Institution of Civil Engineers, for the details of the shafts shown.

DISCUSSION.

The PRESIDENT, in asking the meeting to pass a vote of thanks to the author, said that the paper was one which it would be much better to have studied leisurely and quietly before offering any criticism upon it. He considered that it was a most valuable contribution to their professional literature, as the subject was one which required a paper like that of the author, because some of the theoretical calculations were hardly applicable to the conditions which practically existed; and the failure of some well-known shafts could be attributed to the want of better data as to those conditions, and this the author had evidently realised. Several valuable observations had fallen from him during the reading of the paper, which it was hoped would be recorded. He (the President) would point out that no allusion had been made to the effect of synchronous action of the wind. His own view was that the maximum coefficient of wind pressure did not express the most trying conditions to which a chimney shaft was exposed. The synchronous action of a wind of not very great velocity would produce a much more disastrous effect upon a structure than a high wind pressure acting continuously and uniformly.

Mr. A. T. WALMISLEY said that he could not, on simply hearing the paper read, assent to the author's condemnation of Professor Rankine's views on this matter, but no doubt a careful perusal of the paper might lead them to agree with him in a great measure, if not entirely. The meeting would feel very much obliged to the Author for bringing this subject before them, because the data upon which they had to work could not be too accurately settled or too much discussed. The author had not referred to the foundations of chimneys, which are intimately connected with the question of stability. It happened, however, that chimneys very often failed from bad foundations. He had seen a very notable instance at Bradford, in which a chimney fell at Newland's Mills, Spring Mill Street, belonging to Sir Henry Ripley. That chimney was projected in the year 1862, and the contract was let in a fashion which he was sure many in that room would disapprove of. The experience of the contractor, who was no doubt a very competent man, was trusted, and the chimney was commenced without either plans or specifications being prepared; the only condition was that the chimney was to be built at an agreed price. It was designed to be 80 yards high with a 9 ft. flue, and a base of 24 ft. square. It was agreed that it should be founded upon a good bed of concrete. Subsequently, the design of the chimney was altered,

and, to make it more ornamental, openings and panels were to be put in. The site selected for the chimney was an old coal shaft. The pit was filled in with concrete, forming a central pillar, upon which was placed a concrete table, 2 feet thick, supported also at the corners by four other pillars; so that the chimney was built upon a table of concrete which stood upon five legs. The old shaft itself was filled in and carefully packed, as was supposed, with stone and oak wedges. In the limited space, however, it would be very difficult indeed to pack properly, and at the best the foundation could not be so substantial as if it had been on the solid. The fall happened upon the 28th December, 1882. There had been no violent gale the night before; the wind pressure was recorded as only 16 lbs. on the square foot, or, say, half a gale. The chief cause of failure was undoubtedly the imperfection of the foundation. The chimney had been repaired from time to time because cracks had been noticed. At first it was supposed that only the outside casing was affected, but, a few months before the destruction of the chimney, the cracks began to develop and bulges took place. His only object in stating these particulars was to enforce the importance of carrying foundations down to a solid base.

Mr. C. MOLYNEUX said that, as to the value $\frac{1}{2}$ given by Rankine for the coefficient on a cylindrical surface, of which the author had spoken, his attention was drawn to it when he was looking into the subject, and he also noticed in Molesworth's Pocket-book a statement that the wind pressure was in theory $\frac{2}{3}$, and found in practice to be $\frac{3}{4}$, on a cylindrical surface as compared with a flat one. He had failed to find anything to support that statement, and had therefore adopted Professor Rankine's value. Beaufoy's experiments on bodies of various shapes moved in water, also, did not appear to support any coefficient so high as $\frac{2}{3}$. He and Mr. Wood had subsequently received a letter from Glasgow, from Professors Alexander and Thompson, stating that the coefficient was $\frac{1}{2}$, and giving a mathematical proof. He saw no reason at present why they should depart from Professor Rankine's value of $\frac{1}{2}$, though he must say that he was himself under the impression that in the Mechernich and other round shafts the coefficient must be higher; but that impression rested only on his own judgment, not on calculation. So far, therefore, he agreed with the writer of the paper. As to the limit of deviation, it was several years ago that he looked into the question of the true value of Rankine's symbol, q. He noticed at that time what the author had drawn attention to with regard to it, viz., Rankine's statement that it was near enough for all practical purposes, to take $q = \frac{1}{3}$ for

square chimneys in one case, and $q = \frac{1}{4}$ for round.* Rankine's formula was $h^2 + h_1{}^2 \div 6$ or $8\ h^2$, as the case might be, h being the outside diameter and h_1 the inside. He had found in looking into the matter that if they were to apply that formula to small shafts (say under 100 feet high), the height adopted in practice for a given cross-section would have to be greatly reduced—often to one-half. For instance, he found in the case of a square shaft 74 feet in height, that had actually been standing for seventeen years, that the overturning wind pressure worked out by formula at 26 lbs., yet that shaft stood in a well-exposed position. Another example was that of a square shaft, 99 feet high, which worked out at 29 lbs. While he agreed with the author that it was not correct to take $\frac{h}{3}$ or $\frac{h}{4}$ in the case of a small shaft, he considered that, with so simple a formula, there was no reason for not adopting the accurate value (corresponding to the middle line on the author's diagram, Fig. 5) rather than any approximation, even though on the safe side as regards stability. In a published method by another writer, the centre of the masonry had been taken as the limit of deviation, which was in error on the wrong side. Under all the circumstances, and until the question between sin ^{2} and sin ^{3} for instance, was definitely settled, he thought they would do well to follow so high an authority as Professor Rankine, in adopting the coefficient $\frac{1}{2}$, and taking the high wind pressure of 55 lbs. The shafts which had been designed on that principle had all stood safely. He had heard it stated that Professor Rankine's great shaft at St. Rollox rocked in a high wind. Whether that was so he did not know, but it seemed contradictory to all theory. He had worked out by the formula the value of q on the St. Rollox shaft, and found that it was at every joint 0·22. The overturning wind pressure would therefore be 49 lbs. per foot, instead of 55 as obtained by Rankine's approximation. The point which had been touched upon by the President—the synchronous action of the wind—seemed to him to be a very important matter. The period of oscillation of a large shaft, if assumed as free to swing, was easily worked out. With a shaft 30 feet in height it would be about two seconds. If, therefore, the wind occurred in gusts of two seconds' interval, the effect would be to increase the vibration. It was a matter more for mathematicians than for

* Professor Rankine's actual words are (A. M., p. 242) "Chimneys in general consist of a hollow shell of brickwork, whose thickness is small as compared with its diameter; and in that case it is sufficiently accurate for practical purposes to give to q the following values :—

for square chimneys $q = \frac{1}{3}$; for round chimneys $q = \frac{1}{4}$." Ed.

engineers to discuss, as to what would be the action of the wind under those circumstances, and whether a fluid like the air was subject to such vibrations. In one instance, during a very severe gale abroad, he thought he noticed waves of air, rocking everything as if they were waves of the sea itself. The storm was so severe that almost every other house or barn for thirty miles was partly unroofed.

The PRESIDENT said that if Mr. Molyneux would give the calculation which had been furnished to him by Professors Alexander and Thompson, the Society would be glad to have the information and to publish it in the Transactions. He then asked Mr. Coventry, who has been associated with the author in the preparation of the paper, to give the meeting his views.

Mr. W. B. COVENTRY said that, his name having been mentioned in connection with the paper, he wished to express his thanks; but his part had been a subordinate one, and whatever he was able to contribute to the subject had already been given through the author of the paper.

Mr. HENRY ADAMS said it appeared to him that in this paper a great deal depended upon the value of the coefficient.

FIG. 9.

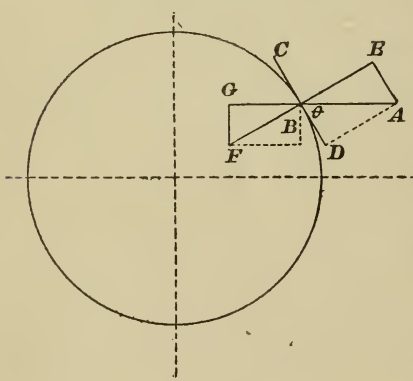
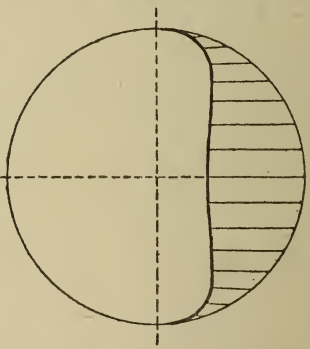


FIG. 10.



He did not follow the author in the production of the sine [3]; but he agreed with him that Professor Rankine's coefficient was too low. He, however, would increase it beyond the ·67 of the author, and, if he might be allowed, would show them how he arrived at his result. Let Fig. 9 represent the plan of a circular chimney shaft, with the wind blowing in the direction A B, and let the length A B drawn to scale represent a wind pressure of p lbs. per square foot upon a normal surface. Then the wind striking at point B (selecting this one point for

illustration) makes an angle of θ with C D, the tangent to the curve at B, and, completing the triangle A B E by the parallelogram of forces, E B = p sin θ is obtained as the pressure acting upon the masonry perpendicular to the tangent, the other component sliding off. Transferring the length E B to B F inside the curve, for convenience, and drawing the right-angled triangle B F G, there results B G = p sin ^{2} θ, as the reduced value of A B acting to overturn the chimney. Repeating this operation at a sufficient number of points round the semi-circumference, and joining the extremities of the lines corresponding to B G, the graphic curve represented in Fig. 10 is produced. But the wind presses upon the *actual surface* of

Fig. 11.

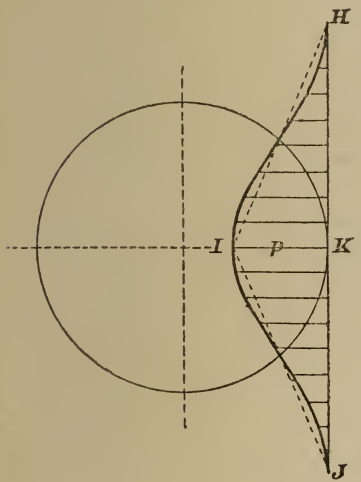
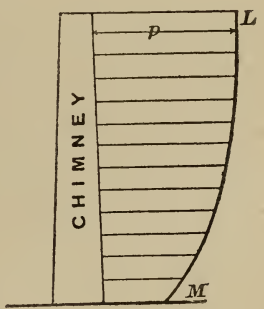


Fig. 12.



the semi-circumference, and, to obtain the mean pressure, clearly this may be developed as a straight line of similar length when, setting up the ordinates previously found and joining their extremities, the curve H I J (Fig. 11) will be formed, which departs from the straight lines H I, I J, equally at the four loops, so that the mean lengths of the ordinates would be ·5 p, I K being equal to A B or p. The same result is obtained algebraically by taking the mean of the squares of the sines for equal angles round the semi-circumference. So far the coefficient agrees with Rankine's; but instead of this mean pressure being taken as acting on the diametrical plane of the chimney, he (Mr. Adams) would take it as acting upon

the semi-circumference, or $HJ = \pi \frac{d}{2}$, so that the total effective pressure, per unit of height, would be $0{\cdot}5\ p \times \pi \frac{d}{2} = 0{\cdot}7854\ p\,d$, instead of $0{\cdot}5\ p\,d$, as used at present, or $0{\cdot}67\ p\,d$, as proposed by the author.

He had been hoping that they should get some information upon the effect of the wind at different heights from the ground, and upon the formation and effect of a vacuum on the leeward side of the chimney. It was generally supposed that near the ground the friction with the earth and the surrounding obstacles held back the wind, so that a varying pressure resulted. It had never been properly tested, so far as he was aware, but he supposed it would give a curve like Fig. 12. Any information on these points would be very valuable to designers of tall chimneys.

Mr. J. H. CUNNINGHAM said that the pressure of wind at different heights was an interesting subject, upon which Mr. Thomas Stevenson had made experiments.* The effect of tornadoes was another subject which might be considered by those who designed chimneys. It had been ascertained † that a whirlwind or tornado sometimes exerted an enormous pressure on a short portion of a long bridge, and the same kind of effect might perhaps be produced on a short portion of a high chimney. It had been remarked that hitherto it had been customary in designing chimneys to assume wind pressures which were now thought by many engineers to be excessive. But before reducing these values to the amounts which recent experiments seemed to warrant, it might be prudent to take into consideration the effect of an exceptionally great wind pressure, acting on a portion of the structure.

Mr. H. STOPES said that nothing had been said with regard to the volume of heat passing up the chimney, and the best method of protecting a chimney from an ascending column of heated air. In the bulk of factory chimneys the volume of heated air was a very important factor indeed with regard to the final stability of the structure. He once had to design a chimney, 140 feet high, which was within touching distance of a building 120 feet high. He had thus a splendid opportunity of observing the effect of wind on the chimney, being so close to a building which it was fair to assume did not move, as it was not only very solid as a building, but heavily loaded

* 'Journal of Scottish Meteorological Society,' vol. v., p. 348, and *post*, p. 210.

† 'Transactions, American Society of Civil Engineers,' vol. x., p. 143, May 1881.

also. The movements of the chimney, relatively to the rigid building, were most eccentric, and each movement was an important factor in the question of its stability. It was necessary to be careful in designing the foundation, because the chimney was within a few yards of the South-Western Railway, and vibration might be anticipated. As a matter of fact, when express trains were running past, the chimney moved in a different manner from that it had when swayed by the wind. It would oscillate as much as three inches, with a wave-like vibration.

Mr. MOLYNEUX said that a point not yet referred to in the discussion was the weight of the brickwork. He found in taking out the weight of some shafts that the weight per cubic foot worked out at 120 lb. to 121 lb. The stone coping, &c., must be taken into consideration. The author gave 105 lb. under ordinary conditions, but for the table of batters (page 168) he used 112 lb.; he (Mr. Molyneux) believed that 115 lb. was the highest value generally adopted.

Mr. ARTHUR RIGG said that, the paper being on the stability of chimneys, it was not, perhaps, quite in order to discuss the question of the draught; but he would make a few remarks on that subject, since it was for the production of a draught that such structures were erected at all. The chimneys shown on the diagrams seemed to taper smaller as they went up. That form of design opened a very large question as to what were the best proportions of chimney, for it was obviously desired to produce the best draught in the boiler by the lowest possible temperature of escaping gases. As these gases ascended they cooled to some extent, and moved more and more slowly as they rose higher; if this were all, a chimney ought to be larger at the top than at the bottom. But in cooling they were becoming reduced in volume, so that the combined effect of the slower speed and reduction in volume led one to conclude that a chimney shaft ought to be parallel inside, or nearly so, throughout its height. Of course, all the rules of stability would hinge upon the proper shape of the chimney; and he thought that it would be better to construct chimneys larger in diameter, and not so tall as the usual practice has hitherto been in this country, following in this respect the example of French engineers.

Mr. W. H. THELWALL said that a few months ago he designed a chimney for South America, using Rankine's formula, and taking the English brick as representing the size of the bricks which would be used in the contract. Fortunately before the designs were sent out some sample-bricks were sent over, and he found that they were only $8\frac{1}{4}$ inches long, and less than

4 inches wide. On going through the calculation again he found that, according to the formula, if these bricks were used the chimney would not be safe, and therefore it was necessary to re-design it. He had thought that it might be useful to put this fact on record for the information of those who designed chimneys for foreign countries.

Mr. Perry F. Nursey said that, with regard to the rocking of tall chimneys, he had heard as an undoubted fact that the St. Rollox chimney did rock. He was in Glasgow about two years ago, and, on a windy day, he went over to St. Rollox to see whether there was any effect noticeable from below produced upon the chimney by the wind, but he could not see any, owing probably to the great height of the chimney, about 450 feet. At Bolton there was a very fine chimney of octagonal form, built in 1842. Its height was 366 feet, and the base was about five times the diameter of the top, which proportion gave a very elegant appearance. The cost was about 3000*l*. Referring again to the rocking of chimneys, he might mention an instance of a chimney which was built by Messrs. Cubitt at their works at Pimlico. It was 105 feet high, with an internal diameter of 5 feet throughout. The brickwork at the bottom was 14 inches thick, tapering to 6 inches at the top. The chimney was built inside a tower, for the purpose of being disguised and appearing more ornamental. The tower was 17 feet square, with 14-inch brick walls, and had a stairway inside. From the top of the tower, the chimney itself could be easily put in motion by the hand. It had been stated that an economy of fuel resulted from this chimney, because the loss of heat by radiation was less. Messrs. Broadwood, at their pianoforte factory in Westminster, had a circular chimney built within a square tower, and they used the space between the chimney and the tower for seasoning their timber, and thus utilised the moderate amount of heat which radiated from the chimney, which would otherwise have been wasted.

Mr. J. W. Peggs regarded the paper as a valuable contribution to the Society's Transactions. The question of wind pressures was very interesting and extremely important to the engineer, entering as it does into the calculations of stability of so many structures. It had been thought by many that, after the Tay Bridge disaster, some steps would have been taken to appoint a duly qualified committee to examine into the whole question, and it was considered that the Institution of Civil Engineers should have led the way in dealing with such an important subject. More observations were wanted with reliable pressure instruments, and especially as to the force of sudden gusts of wind. He hoped that this society would be very guarded with

reference to throwing over the old value of 56 lb. on the square foot. In the great gale of the 13th and 14th October, 1881, the pressures at Greenwich were registered as high as 53 lb. on the square foot, while at the same time the pressures at Lloyd's, in the Royal Exchange, were not more than 26 lb. He agreed with what had been said as to the increase of wind pressure at increasing heights from the ground. He investigated the gale of 1881 rather carefully, with the view of deducing the pressure of the wind from a consideration of the buildings overturned by that gale. He hoped that Mr. Hutton would give the meeting his calculations about the Mechernich chimney, where he said that Rankine made the overturning wind-pressure 70 lb. to the square foot, but that he himself would make it 32 lb. During the gale of 1881, the pressure of the wind-gusts was taken by means of a special apparatus fitted on the top of a large gas-holder, which was being constructed at the South Metropolitan Gasworks. It was found to be about 26 lb. to the square foot. While speaking of chimney shafts, he would like to call attention to the fact that the large chimney-stacks which were built for domestic purposes were often very unsafe. This was fully shown by the large number which were blown down in the great gale of 1881. In an instance which had come under his notice, a chimney-stack in Mecklenburgh Square, of about 20 feet in width, had been thrown over, breaking its way through an adjoining roof. The accident was due in a great measure to the brickwork not having been kept in proper repair. The mortar had weathered out to the extent of $\frac{5}{8}$ inch.

Mr. W. N. Colam wished to question the statement that the wind pressure always increased from the ground upwards. Some experiments which were being carried out at the Forth Bridge by Mr. Benjamin Baker and Sir John Fowler, but which were not yet completed, had proved conclusively that the wind pressure at the top of the bridge was not so great as it was half-way down. He should think that the same result might sometimes be found if tests were made on chimney shafts.

The President said that they had reason to hope that Mr. Baker would give the Society some of the results of his experiments.

Mr. Hutton, in replying on the discussion, said, with reference to the remarks of Mr. Walmisley, that he (Mr. Hutton) had not included the question of foundations or pedestals. In very large chimneys, pedestals were not generally used; and he assumed that the foundations would be matters of ordinary engineering practice. Mr. Molyneux objected that the experimental co-efficients for various forms did not agree with his theory. That was quite true, but it rather pointed to taking a theory which

was of uniform application, than taking experiments which did not seem to obey any law among themselves. To any form of surface they could apply the law of Hutton's experiments. Those experiments followed a fixed law which was very close to the theory, and gave results a little above the theory, but the results fluctuated. Of course he did not suppose that the theoretical co-efficient was necessarily true, but he thought that it was likely to be sufficiently true for the purpose of comparison. He would be glad if Mr. Molyneux would supply in full the formula which had been given to him by the Glasgow Professor. He believed that the standard of wind pressure had been taken too high. Mr. Molyneux had spoken of a shaft 74 feet high; but that height would hardly give any test of wind pressure, for probably the wind would be checked by surrounding houses, unless the situation were very exposed. Mr. Molyneux had said "Why not adopt the correct value for K in all cases?" His (the author's) approximation was nearly the same thing in practice, and was rather more convenient in treating the subject mathematically. Other speakers referred to such matters as oscillation, but he did not see that they could make any other allowance than, instead of calculating the exact K, taking some lesser value which might be assumed to be the extent to which the axis of the chimney departed from the centre of gravity. In the case of Townsend's shaft, it was going gradually till it reached 7 feet 9 inches from the vertical. That was an enormous divergence. He took it from Mr. Bancroft's book. He presumed that the curvature would bring the centre of gravity very much nearer the axis than 7 feet 9 inches. It would probably be about 3 feet, and if that change could have been foreseen, the designers would have taken K at 3 feet less than the calculation, to allow for the divergence. But in general some allowance ought no doubt to be made.

As to the rocking of chimneys, the only provision that he knew of that could be made was to collect information as to how much they rocked, so as to allow for a certain displacement of the centre of gravity. He thought that the shaft could not be treated simply as a pendulum, but that the modulus of elasticity would have to be taken into account in estimating the amount and period of oscillation.

Mr. Cunningham had referred to Mr. Stevenson's experiments and formula for the variation of wind pressure at different heights. Mr. Field had also given a diagram which agreed very closely with that formula. Mr. Stevenson came to a rather curious result—that the wind increased from the bottom to the top of a lighthouse, the lines marking the increase con-

verging at 72 feet below the ground. Mr. Field made it 75 feet. He (the author) had given a formula in the paper for a uniform variation in the wind pressure, increasing upwards from the ground. The present practice really amounted to taking a mean proportion, which was supposed to be the same for a 53-feet chimney and for a 454-feet chimney. That evidently must be wrong. If there was a variation it must tell enormously in such a difference of height as that; and he believed that an approximation would have to be founded upon experiments, and that a solution would be found more in the direction of Mr. Stevenson's experiments, which were made for lighthouses.

Mr. Stopes had said that a chimney which he designed was found to rock 3 inches. He (Mr. Hutton) thought that but a small movement compared with the oscillation of some chimneys.

Mr. STOPES said that the 3 inches rocking of which he had spoken was caused only by the passing trains. He dared say that the chimney would rock 10 inches in the wind.

Mr. HUTTON said, with regard to a synchronous action of the wind, that it would no doubt be dangerous, but he did not see how it could be met except by increasing the allowance for oscillation to an extent to be arrived at by experiment and the careful observation of many different cases.

He had not wished to leave out of consideration the internal proportions of flues, but he had rather hoped to draw out in the discussion how far a large batter would militate against a good draught, and how far therefore it would be desirable to depart from the economical shape for the sake of the draught. Mr. Nursey had asked for the dimensions of the chimneys illustrated. The Townsend shaft was 454 feet high, 32 feet diameter at the bottom, and 13 feet 4 inches at the top. The St. Rollox was 435 feet 6 inches high, 40 feet diameter at the bottom, and 13 feet 6 inches at the top. The Mechernich was a chimney built in a very exposed position at Dusseldorf. It was 397 feet 3 inches high, 24 feet 8 inches diameter at the bottom, and 11 feet 6 inches at the top, with a batter of one in sixty, which was very steep, and had to be compensated by an enormous thickness of masonry.

He did not know the details of M. Borda's experiments. He had searched a good deal for the particulars of both Hutton's and Borda's. He believed that they were carried out by some system of blowing with a fan. He also found that the cylinders experimented on were mentioned as being very small. As to Mr. Baker's experiments at the Forth Bridge, mentioned by Mr. Colam, he certainly could hardly understand how the wind should be higher lower down than at the top. It seemed

contrary to the usual theory of the diminution of pressure from friction against the surface of earth or water. They all knew that in a narrow valley the wind was much stronger than on either side of the valley, and that might in some way account for the discrepancy. But the valleys, both of the Tay and the Forth, where the bridges crossed, were of considerable width, and he could only suppose that some local conditions caused the pressures observed to be highest near the ground.

Mr. COLAM said that the pressure was highest at the mid-height. Mr. Baker had told him that in very heavy winds the men would work willingly at the top, but they would not work half-way up. In reply to Mr. Cunningham, Mr. Colam stated that the first observations were made at the island in the centre, but latterly they had been making them on each column. The instruments had been up for some time.

The following communication was afterwards received from Mr. Benjamin Baker, in reply to an invitation to state his experiences with regard to wind pressure.

In practice, the disturbing influence of surrounding objects is so great, that it would be hopeless to attempt to arrive at any mathematical expression for the distribution of wind pressure on a chimney shaft. The theory, also, of the subject is still undeveloped. The Author says "theory gives ·67 per cent" as the relation of the pressure on a circular shaft to that on an equivalent plain surface, but in Mr. Baker's opinion his theory is incorrect. Mr. Baker is not aware that any modern authority has ventured to deduce mathematically the pressure on a circular shaft. Lord Rayleigh has done it for the front of a flat plate, but could not deal with the minus pressure on the back of the plate. Helmholtz and Kirchoff have, by an analytical method, obtained some useful results as regards inclined surfaces; but experiment alone is at present available to determine the equivalent pressures of a given wind on differently shaped chimney shafts. Of course, every one who had stood by a circular shaft during a gale, knows that on the windward half of the circumference a part of the surface is under pressure and a part is subject to a "sucking" action, or partial vacuum, similar to that prevailing over the whole leeward half of the shaft. Mr. Baker's experiments indicate that the sum of these pressures is 57 per cent. of that on a plane surface.

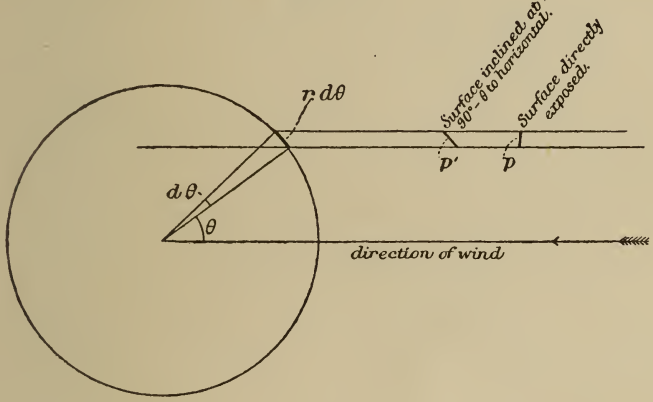
As regards wind pressures at different heights, all depends upon local conditions, such as configuration of the ground and surrounding buildings. To illustrate this it is only necessary to refer to the readings of different gauges at the Forth Bridge

during a recent gale. At 70 feet above sea-level the wind gauge indicated 12 lb. per square foot; at 210 feet, 11 lb. to 15 lb.; at 375 feet, 15 lb. to 24 lb., according to local conditions. On another occasion, with the wind in a different direction, 15 lb. was indicated at 70 feet; 16 lb. at 210 feet; and 14 lb. at 375 feet.

Mathematical demonstration of value ·5 for coefficient of wind pressure on round chimneys as compared with square, referred to by Mr. Molyneux (see his remarks, p. 172), and inserted by permission of Professors Alexander and Thomson.

Pressure of wind on round chimneys:—

Fig. 13.



Let p = pressure of wind per unit area directly exposed.
v = velocity of wind, which will be the same before and after deflection, the direction only being changed.

After deflection through angle ϕ, which is $90°-\theta$, the velocity component in the original direction will be $v \cos \phi = v \sin \theta$.

So that $v - v \sin \theta$ is the diminution in velocity in the original direction.

But $p : p^1 :: v : v\,(1 - \sin \theta)$, where
p^1 = pressure on inclined area, of amount corresponding with that on which p was taken previously.

$p^1 = p\,(1 - \sin \theta)$.

Since the area exposed is greater than that on which p acted originally, the pressure per unit area is diminished, and is

$$p\,(1 - \sin \theta) \cos \theta.$$

The area exposed, taking length of cylinder as unity, is $r\,d\,\theta$, so that the pressure on the small curved surface is

$$p\,(1 - \sin\theta)\cos\theta \,.\, r\,.\, d\,\theta.$$

Integrating from 0° to 90°, we get

$$p\ r \int_{0°}^{90°} \left[\cos\theta\, d\,\theta - \sin\theta\cos\theta\, d\,\theta\right]$$

$$= p\,r \left[\sin\theta + \tfrac{1}{2}\left(\tfrac{1}{2} - \cos 2\,\theta\right)\right]_{\theta=0°}^{\theta=90°}$$

$$= \tfrac{1}{2}\,p\,r\,;$$ or, for the whole surface,

$$= \tfrac{1}{2}\,p\,d,$$

where r = radius, and d = diameter.

November 7th, 1887.

HENRY ROBINSON, PRESIDENT, IN THE CHAIR.

PRIMARY BATTERIES FOR ILLUMINATING PURPOSES.

By PERRY F. NURSEY, PAST PRESIDENT.

INTRODUCTORY.

IF there is one branch of practical electricity, the pursuit of which is more attractive to the electrician and the inventor than another, it is undoubtedly that of the generation of an electric current for illuminating purposes by means of a primary battery. Proof of this is to be found in the hundreds of patents which have been applied for in this connection during the past few years, and in the many attempts, unsuccessful and otherwise, to produce a commercially practicable primary battery during the same period. The reason for the attractiveness of the subject is to be found in the costliness of the steam-driven dynamo electric system, which, as regards small installations, and with all its excellent progress, still leaves a very wide and remunerative field open for a cheap and efficient primary battery. The prize is great, while the means of winning it would appear to be simple enough when understood. We have only to discover cheap and efficient active and inactive elements, and wed them by means of an equally cheap and efficient depolarising medium, and success is achieved. "Far more easily said than done," will be the thought now naturally passing through the minds of all. It is the author's intention in the present paper to endeavour to ascertain how far we have succeeded in producing such a battery as shall conform to the everyday requirements of ordinary life. In doing this, he does not purpose pursuing the subject so much from a scientific as from a practical and an economic point of view. Scientifically speaking, the primary battery for light-producing purposes has long been a practical success. Commercially speaking, it is not yet so, except in special cases, and this, notwithstanding the great strides it has made during the last five or six years in that direction. In treating this subject, the author proposes first to briefly indicate the principles of the primary battery, and to outline its history, and then to describe in chronological order the various batteries of this class which

he has had the opportunity of inspecting from time to time as they were introduced to public notice by their respective inventors.

Principles.

The author may perhaps be excused for referring to the first principles of the primary battery, as such reference may be useful in rendering what follows perfectly clear to some of the junior members of the society, as well as to those non-professional gentlemen who now honour us with their presence as visitors. The principle of the primary battery is exceedingly simple. It depends for its action upon the different chemical affinity of an acidulated solution or other medium for two metals of differing qualities. The most simple and elementary light-producing primary battery is formed by placing a small bent strip of zinc between the teeth and the upper lip and a silver coin on the tongue. Upon closing the eyes and bringing the two metals into contact, flashes of light will be produced in the eyes. Here we have the zinc and the silver as elements, the saliva as a depolariser, the nerves as conductors, and the eyes as lamps. The decomposition of the excitor becomes apparent to the taste. The next step in advance is the production of electricity either by the voltaic pile or the cell. By the cell its production may be compared to the production of heat by a stove. As the coal combines with oxygen under certain conditions, it is burned, and produces heat. In like manner, if we place zinc in a condition favourable to its combination with oxygen, the zinc is consumed, and that mysterious force which we call electricity is produced. The most primitive form of battery is made by attaching a piece of zinc to one end and a piece of copper to the other end of a wire, and placing them in a vessel containing acidulated water. This constitutes a simple circuit or voltaic pair, by means of which a current of electricity is produced. The water contained in the cell is decomposed into its constituents, oxygen and hydrogen, the oxygen combining with the zinc. This reaction, in conjunction with the metallic contact of the two dissimilar metals, disturbs the electrical equilibrium. The polarity or disturbance commences at the surface of the zinc or active element, and is propagated through the liquid to the copper, or inactive element, and thence back again by the conducting wire. Positive electricity is here assumed for the sake of simplicity, but it must not be forgotten that a current of negative electricity is set up at the same time. In every voltaic combination the passage of the electrical current (that is, the positive modification of the force) in the liquid is from the active to the inactive

element. In the simple circuit just described it is from the zinc to the copper. By bearing this in mind, the positive and the negative ends of a battery will always be readily distinguishable. The positive is the end where the electric current leaves the battery, and the negative where it re-enters. Volta's second battery, known as the crown of cups, is merely a compound circuit composed of a number of simple pairs similar to that just described, and explains the general principles of primary batteries. There are a great number of modifications of this simple form in practice, the basis of construction of most of them being a variation in the method of preventing the hydrogen (by means of evolution or combination of substances having an affinity for it) collecting upon the copper or negative element. Many substances, such as carbon, copper, silver, platinum, and platinised silver, are used as negative elements. In most primary batteries that have hitherto been constructed, zinc has been found to be the best suited for the positive element, as it so readily combines with oxygen.

Historical.

The author has already referred to Volta's pile and to his cup battery, and it need hardly be pointed out that these are to be regarded as the beginnings of the development of this form of electricity. They constitute Volta's practical comment upon Galvani's ingenious but erroneous theories. In 1802 Sir Humphrey Davy multiplied the productive power of Volta's cells very greatly, and was the first to produce an electric light from that source. He used plates of copper and zinc immersed in dilute acid, the light being produced between poles of carbon. In the same year Robertson exhibited an electric light in Paris, which he produced from a voltaic pile of 120 elements of zinc and silver, using carbon poles. A few years later Davy constructed a battery of 2000 cells, and obtained from it a magnificent light. Cruikshank modified Volta's original pile by soldering the zinc and copper plates in pairs, and fitting them in a trough so as to form a series of cells, which were filled with the exciting solution. Wollaston's battery was a further improvement, in which the copper plate was doubled round the zinc plate, the two metals being kept apart by non-conducting distance pieces. Both surfaces of the zinc were thus exposed to the action of the acid. The current obtained in the early batteries, however, was not constant, owing to the polarisation of the battery, that is, the deposition of hydrogen gas upon the copper plate, which offers a resistance to the transmission of the electric current. In Smee's battery this want of constancy was considerably remedied

by the copper plate being roughened, the disengagement of the bubbles of hydrogen from its surface being thus facilitated. Smee subsequently produced a still more constant battery, by using a platinum plate coated with a deposit of very finely divided platinum, a large number of points of small size being produced, and proving far more efficient than fewer points of large size.

Smee's battery, however, was far from constant, and the question arose whether prevention was not better than cure. Smee had attempted a remedy, but Daniell appeared in the field with a means of prevention in a battery which still takes the lead as regards constancy. Polarisation was perfectly prevented, but the electromotive force of the copper-zinc couple was low and the internal resistance high. This is the exact converse of what is required in a primary battery for electric lighting, which, besides constancy, should possess a high electromotive force and a low internal resistance. Grove, however, overcame this difficulty by substituting for the metallic solution used by Daniell a cheap non-metallic depolariser (nitric acid), thus producing a chemical depolarising battery of high electromotive force and low internal resistance. The production of the electric light on a practical scale by means of a primary battery was thus made possible, and Grove's battery was very soon applied for the purpose of producing scenic effects in theatres. Other workers in the same direction followed in due course, and amongst them may be mentioned Cooper, Walker, Bunsen, and Archereau.

Batteries for Special Purposes.

Although the author desires to strictly limit the subject of his paper to primary batteries for light-producing purposes, to the exclusion of those used for telegraphic and signalling purposes (which would afford abundant matter for a separate paper), he thinks it well to notice in passing one or two of these latter which have been modified for the purpose of producing light for special purposes. The first of these is the Victoria Leclanché battery, one of which is on the table. Here the positive element is zinc, and the negative element either carbon surrounded by peroxide of manganese and coke, or the modified arrangement of carbon and peroxide blocks. The exciting fluid is a solution of sal-ammoniac. These batteries have a very low internal resistance and improved constancy, and are useful where great quantity and constancy are required, as for lighting small glow lamps for surgical and other purposes. The bichromate battery, one of which is on the table, is useful for experimental lighting purposes. The positive element is zinc, and the negative element

carbon, the excitor being a solution of either bichromate of potash or bichromate of soda. A third battery of this class is the Bunsen battery, in which the positive element is zinc in an outer jar, and the negative element carbon in an inner porous pot, the exciting solutions being prepared with sulphuric acid for the zinc, and either nitric acid or nitrate of soda and sulphuric acid for the carbon. An example of this battery is also on the table, having, with the two already noticed, been lent the author by the General Electric Apparatus Company.

Conditions Required in Batteries for General Lighting.

Having thus led up to the subject proper of his paper, namely, primary batteries intended for general lighting purposes, the author will next proceed to describe those batteries which have come under his personal notice during the past four years. He would, however, first observe that any battery, to be of use for practical electric lighting on a broad and general scale, must fulfil, amongst others, the following leading conditions:—

1. It must be capable of producing a constant current.
2. It must possess a fairly high and constant electro-motive force and a small and constant internal resistance.
3. The elements and the excitor should be of a simple, innocuous, and inexpensive character, and should not give out noxious or even unpleasant fumes.
4. There should be no waste going on whilst the battery is not doing work.
5. It should be capable of being cleansed and replenished easily and without any kind of personal danger from any source.
6. It should be of small dimensions, and capable of being managed by the most ordinary capacity.

The Holmes and Burke Battery.

The first primary battery that came under the author's notice was that of Messrs. Holmes and Burke, which was brought out in November 1883, and constituted then a new departure in the practice of electric lighting. All the information the author could at that time obtain respecting it was that the elements were carbon and zinc, and that the essence of the invention consisted in the mechanical arrangement of the battery and the nature of the excitor. The author saw a large room lighted by a number of Swan glow lamps of five-candle power each, which derived their current from batteries placed in an adjoining

room. It was stated that a sixteen-cell battery was equal to the supply of eighteen glow lamps of five-candle power each. The author saw also a railway carriage lamp of considerable power driven from the Holmes battery, and was informed that a battery and some lamps were in practical use, as fitted in a carriage running with the 5.40 P.M. express train from King's Cross to Leeds on the Great Northern Railway. It was stated that the light was kept switched on during the dark hours and in tunnels, whereas in daylight the current was switched off, when practically there was no waste in the cells. Thus the battery performed four journeys (there and back twice) travelling about 750 miles, which, allowing for the train standing at each terminus, occupied in all, say, twenty hours, and even then there was said to be four more hours' life still in it. With regard to cost, it was stated that the light was maintained for twenty-four hours, at an average rate of one-eighth of a penny per light per hour—i. e. one penny per eight hours' continuous light; but that the expense varied with the size of the lamps and the amount of electricity used. As no particulars were given of the construction or equipment of the Holmes and Burke battery, no opinion of its practical or commercial merits can be formed. It is worthy of note, however, that Messrs. Holmes and Burke were, so far as the author is aware, the first to contest the field open for primary batteries for general lighting purposes. Installations of this system have been fitted up in several houses, including that of one of our members, Mr. A. F. Yarrow, who recently informed the author that the battery had worked very satisfactorily during the three years it had been in use.

The Holmes and Burke battery has lately been improved by Mr. W. Webster, jun., managing director of the Railway and Domestic Electric Lighting Company, and Mr. Octavius March, their electrician, who have afforded the author the following particulars of the improvements. The best known depolariser is no doubt nitric acid, but the difficulty of using it in a battery constantly in use has long been recognised. The depolarising fluid in the new Holmes and Burke battery is one in which the advantages of nitric acid are obtained without the disadvantages. This is done by using the materials from which nitric acid is made, in such a way that the nitric acid required for depolarisation is generated in the battery by the electrochemical action. This generation ceases when the battery is at rest, and consequently there is never any free nitric acid present in the cell. The battery is a double fluid one, using a special depolarising fluid with carbon plates in a porous cell, and having zinc plates in the outer cell with dilute sulphuric

acid. The working E.M.F. of the battery in open circuit is 1·8 volt. The fall of potential during discharge is almost nothing. The internal resistance of the sized cell generally used is 0·03 ohm. Consequently a discharge of 10 ampères can be obtained at an E.M.F. of 1·5 volt. The principal constituents of the fluid are nitrate of soda, the cheapest salt obtainable (except sodium chloride), and sulphuric acid, the cheapest acid. The cells are usually arranged in sets of eight, and provision is made for filling and emptying eight cells simultaneously.

Great difficulty is usually experienced in preventing the various connections and contacts from corroding. Mr. March finds the best method is to dispense with all binding screws, and to obtain the necessary contacts by means of mercury cups of a special form. In the latest form of the battery the company have also been able to dispense with wooden tops or covers, the necessary recesses for the mercury connections being formed in the stoneware of which the cell is made. The plan now adopted also adds materially to the ease of manipulation, as a zinc plate can be taken out for inspection and amalgamation at any time without breaking the main circuit.

The cost of material for maintenance may be taken to be as follows:—Sixteen cells will maintain ten 10-candle-power Swan lamps for about twenty hours. The cells usually hold about 3 pints of fluid per porous pot, or 6 gallons for the sixteen; this at 9*d.* per gallon = 4*s.* 6*d.*; acid for outer solution, about 1 gallon, 1*s.* 6*d.*, together = 6*s.* The work done would be about 5 electric horse-power-hours, and the zinc consumed (about 2 lb. per electric horse-power-hour) would amount to 10 lb. at 3*d.* = 2*s.* 6*d.*, bringing the total up to 8*s.* 6*d.* This gives 200 lamp hours for 8*s.* 6*d.* = 0·5*d.* per lamp hour. The cost of a gas burner giving about the same light with gas at 3*s.* 6*d.* per 1000 would be 0·21*d.* It is only right to add that these conditions can only be obtained where a battery is properly attended to. Great waste naturally takes place where there is neglect. The time requisite for attending properly to a 16-cell battery should not exceed from one-quarter to half an hour daily for examination, and one hour for charging and amalgamating once or twice a week according to the amount of current used. By the courtesy of the Railway and Domestic Electric Lighting Company a set of eight cells composing a Holmes and Burke battery, driving twelve Swan 5-candle-power glow lamps, is here in illustration of the system.

The Ross Battery.

The next example of this class of generators came under the author's notice in December 1883. This was the primary battery of Mr. O. C. D. Ross, in which the special merits claimed were economy and constancy. In this battery zinc plates were used, and the liquid electrolytes were stated to be of an inexpensive character, and the consumption of zinc so small that it only represented a cost of 2*d.* per hour for the electrical unit. By a simple arrangement the cells could all be simultaneously charged with the liquid excitor, and subsequently discharged by merely raising or lowering a framework of tubes and turning on and off a tap. The zinc which was consumed in the battery was recovered in a solid form and in augmented quantity as oxychloride of zinc. This product, it was stated, formed the principal ingredient of a new insulating material for covering electric conductors. It was found that with a single charge of the chemical liquid a substantially constant current could be obtained for upwards of twelve consecutive hours. That point was verified by the report of a professional tester, who carried out a series of experiments with a few cells forming a portion of this battery. Upon the occasion of the demonstration at which the author was present, a Swan glow lamp, stated to be of 100 candle-power, was first shown, after which thirty-nine Swan lamps of 10 and 7 candle-power were lighted. Twenty Woodhouse and Rawson glow lamps, each of 20 candle-power, were subsequently shown, and during the time they were running, the current was switched on to a motor which drove a 16-inch Blackman ventilating fan with but slight detriment to the light of the twenty glow lamps. A powerful arc lamp was also brought into action, all the other sources of consumption of current being of course switched off. In all cases the light was of good quality and very steady, and in these respects the demonstration was very satisfactory. The arrangement for charging and discharging the cells was very good, but the battery was very large in proportion to power, and emitted a decidedly objectionable smell. The nearest approach to an estimate of the cost of the light produced was that it was slightly more expensive than gas. As the battery was working in the City of London, the price of gas may be put down at 3*s.* per thousand. Mr. Ross recently informed the author that his battery had been successfully applied to the lighting of a house in Queen's Gate for two years. Mr. Ross, however, does not now attach any importance to the recovery of the oxychloride of zinc as a by-product, for the reason that

in house-lighting the quantity would be too small to make it worth collection. Mr. Ross informs the author that quite recently he has made a discovery in connection with the action of the separate cells of his battery, which will greatly simplify the daily manipulation of discharging the spent solution and replenishing the cells with fresh.

The Coad Battery.

In January 1884 the author inspected the working of the Coad primary battery, which had been publicly exhibited previously, and had then recently undergone several modifications and improvements. No particulars were given as to its construction, beyond the statement that the battery had a specially prepared zinc element immersed in a special liquid excitor, one feature being that the zinc was not removed from the bath during non-use, there being, it was said, no waste. The battery appeared to be of small size for its power, inasmuch as two batteries of ten cells each were contained in a case 3 feet high by 2 feet wide and 20 inches deep. Each 10-cell battery was said to be equal to the supply of one Swan glow lamp of 20 candle-power, and it was stated that the battery would give a full-light for forty hours, after which it had to be recharged with the liquid. The cost of maintaining a battery of 10 cells for forty hours was put at 1*s.* 3*d.*, and each cell was said to yield a large quantity of chrome. The glow lamps gave an excellent light, and so far as it went, the demonstration was satisfactory. The author, however, has not heard of this battery since the date given, and his recent attempts to trace it have proved futile.

The Lalande Battery.

About the middle of 1884 a considerable amount of attention was being directed to the Lalande-Chaperon primary battery, by means of which it was claimed that a current of electricity could be generated and used either for lighting or for driving machinery, and that certain of the elements which produced the current became converted, during the time they were doing their work, into a substance of greater value than they possessed before the battery was started. The battery was somewhat large, that which the author inspected being composed of forty-eight cells, each 1 foot cube. It was stated that this battery was capable of maintaining fifteen glow lamps of 10 candle-power each, or of driving a small motor. Each cell of the battery consisted of an iron tray, on the bottom of which was placed the depolarising agent, which was oxide of copper.

Just above this and supported at each corner was a plate of zinc, the cell being filled with a solution of caustic soda. Under ordinary circumstances, and when the circuit was open, no action took place between these elements; but on the circuit being completed, the work of decomposition commenced. The oxygen of the oxide of copper combined with the zinc, and formed oxide of zinc, metallic copper being left behind. When the battery was exhausted, the zinc was recovered from the liquor in the form of an oxide, and this was stated to be 56¼ per cent. more valuable than the metallic zinc, and was to be used for making paint and for other industrial purposes. This remarkable increase in value was said to be obtained by reason of the metal having gained 25 per cent. in weight by its absorption of oxygen, and the oxide being also 25 per cent. more valuable than the metal, weight for weight, thus giving a total increase in value of 56¼ per cent. as stated. The oxide of copper was to be revivified and used over and over again. The claims mainly advanced for this battery were, that it was absolutely constant so long as the elements in it were kept in a state of efficiency; that the action upon the zinc was very gradual; that, while the light was not being used, there was no waste going on; and that no noxious smell was given off, as is the case when acids are used. This latter point was clearly demonstrated upon the occasion of the author's inspection, as was also the ability of the battery to give an excellent and steady light. A series of nine Woodhouse & Rawson glow lamps, each of 10 candle-power, were used in circuit. An Ayrton & Perry motor was driven by the current, and showed the battery to be capable of doing good work in that respect. The cost of the light produced was stated to be much less than that of gas.

Although the battery is the invention of M. Lalande, the credit of attempting to utilise the residual product from it is due to Mr. J. Berger Spence, head of the firm of manufacturing chemists bearing that name. And it came about in the following manner:—The manufacture of oxide of zinc is in ordinary a costly process, and Mr. Spence had for some time past been casting about for a more economical method. Amongst other things, he tried electrical decomposition; and, whilst engaged in his experiments in that direction, he became acquainted with M. Lalande, who, he found, had a battery which was giving exactly the result Mr. Spence wanted. The introduction of the battery for lighting purposes, however, is due to Mr. Hugh A. Fergusson, under whose hand it has been considerably modified and improved since the author saw it in June 1884.

In the improved battery the elements consist of zinc, caustic potash, and oxide of copper. The cell consists of a cast-iron trough, 24 inches long, 12 inches wide, and 18 inches deep, holding about 15 gallons of liquid. The negative plate (positive pole) consists of folded iron gauze, into which is pressed an agglomerate mixture of oxide of copper, in a granular form (copper scales), and chloride of calcined magnesia in certain proportions. This, when heated, forms a hard porous plate. The oxide of copper acts as a depolariser, and is the essential feature of the battery. When the battery is worked out, the copper is left in a metallic form, and by heating the plates in a furnace it is reoxidised, and again ready for use. The size of the plates is 20 inches long by 18 inches deep and $\frac{3}{8}$ inch thick. There are four in each cell, presenting a working surface in the liquid of about 1280 square inches. Each plate contains about 10 lb. of copper, or 40 lb. per cell.

The positive plate (negative pole) consists of a zinc plate, of which there are two in each cell. The dimensions of each being 20 inches by $15\frac{1}{2}$ inches by $\frac{1}{4}$ inch, and the weight 20 lb., or 40 lb. the two in each cell. The working surface is about 1240 square inches. The exciting liquid consists of a solution of caustic potash at a specific gravity of between 1·25 and 1·3. The electro-motive force through high resistance is stated to be slightly under 1 volt. In the earlier experiments the lamps were run direct from the battery, and although this answered very well in many cases, there were found to be objections to this method. The battery is therefore now worked in combination with another battery of secondary cells or accumulators, which are charged in parallel from a set of six primary cells in series. This system of charging accumulators in parallel is found to answer very well, as the cells are more evenly charged than in the series system. The secondary cells are connected to a switch for turning them into series and on to lamp circuit, or in parallel and on to battery circuit. By this means, not only are the objections connected with running a lamp circuit direct from primary cells avoided, but there are said to be collateral advantages of great importance in connection with the system.

Several installations of the Lalande system have been fitted up in London and elsewhere, and are reported to have given every satisfaction. In practice the cells are placed in a cellar, from which there is an opening to the street sufficiently large to pass the plates and primary cells through. When the solution had become saturated with zinc, it was formerly removed by means of a tank cart, into which the exhausted solution was put. In the future, however, a vacuum cart is to be used in order to save time. By this means a battery of 6

cells, holding 90 gallons, will be emptied in ten minutes. The company working the invention will maintain the batteries, and the carts will visit the houses where they are in use at stated periods to re-charge them whenever it is necessary. The specific gravity of the solution in the primary cells acts as a reliable indicator of this. The solution is to be taken to the works, where it will be treated in two ways. First, by the process invented by Dr. Squire, by which the zinc is obtained back in the form of sulphide of zinc, and is sold for paint-making purposes; and, secondly, by the process invented by M. Lalande, by which, it is said, the zinc is obtained back in a greater state of purity than when it was originally put into the battery. The caustic solution will also be brought back to its original condition, and the oxide of copper gauzes will be re-oxidised for further use. This latter process has only been completed within the last few months, and by its means it is claimed that electricity can be supplied at a lower cost than has yet been supposed possible. The Lalande system, as a whole, has been examined by several scientific men, and the reports that have been made by them are very satisfactory. The reporters, as regards the electrical part of the system, were Professor Tait and Professor Crum Brown, of Edinburgh, and Principal Jamieson, of Glasgow. The chemical part has been examined by Professor Dittmar, of Glasgow.

The Lalande system is illustrated by a battery of six dry cells, with fifteen Swan-Edison 10-candle-power glow lamps running from ten accumulators charged at the works, which Mr. Fergusson has kindly placed at the author's disposal upon the present occasion.

The Skrivanow Battery.

The attempt which was made in the early part of 1885 to destroy the Houses of Parliament by dynamite led to the introduction to public notice of a new search light driven by a primary battery, and designed for use in small boats on rivers. It was introduced by Mr. Isidore Spielmann, who about the time stated experimented with the apparatus, which was in the first instance intended for the use of the river police in patrolling the Thames opposite the Houses of Parliament. The object was to throw a strong light from the middle of the river on to the Palace of Westminster. The difficulty to overcome was the obvious one presented by the size of the police boats, which does not admit of their being fitted with engines, dynamos, or bulky accumulators. The only source left was that of the primary battery, and from this was derived the light with

which the trials were made. The battery used was the invention of Mr. George de Skrivanow, a Russian inventor, who died about that time. The elements of this battery consist of a small packet of chloride of silver and two plates of zinc placed in each cell with a weak solution of caustic potash. In applying this battery to domestic lighting, a small one is placed in the stand of a moderator or other similar kind of lamp, which can thus be utilised for the purpose, a glow lamp being fixed on the top in place of the ordinary burner. The author inspected a number of lamps thus arranged. Taking one as typical of the rest, he may explain that it had a battery consisting of three boxes, each measuring only 4 inches by 2 inches by 1 inch, which supplied the current to a glow lamp of Italian manufacture, the light being an exceedingly good one. It was stated that it would burn for twelve hours with undiminished brilliancy, but that at the end of that time the silver would be converted into pure silver, and would require to be revivified. This is effected by washing it in a solution of nitric and hydrochloric acid. It is then replaced in the battery for further use, there being no waste of the silver. The marked advantages of this system of domestic electric lighting, beyond the portability of the lamps, are the absence of fumes, the small battery capacity, and the high electro-motive force, this being $1\frac{1}{2}$ volt for each cell, which is only 1 inch in width. Applied to the arc system, the Skrivanow battery showed its power, a light of 250 candles being produced from a couple of batteries measuring 10 inches long by 8 inches wide and 6 inches high. This installation, which the author also inspected, was, in fact, the one already referred to as having been used as a search light on the Thames by the police.

The Skrivanow battery was also applied to a miner's lamp, and an example was brought under the author's notice in January, 1886. This lamp consisted of a metal casing 7 inches high by $3\frac{1}{2}$ inches wide and 3 inches deep from front to back, and which contained the battery. Projecting from the front of the case was a 3-candle glow lamp of German make, which was properly protected, and had a reflector. The battery was composed of three cells, each 6 inches by 3 inches by 1 inch, and produced an excellent light of 3 candle-power, which, it was stated, would last nine hours. The current given off by this battery was in excess of the requirements of the miner; but there were smaller lamps, notably one of circular form 3 inches in diameter and 3 inches deep, and of 2 candle-power, burning for five hours. Another, of the quadrangular type, was 6 inches high, and of 3 candle-power, but only burning for seven hours and a half. The cells were hermetically sealed, so there

was no fear of escape of the liquid portion of the contents, and the lamp could be inclined at any angle without fear of extinction.

The Upward Battery.

A decided departure in primary batteries was brought out in July 1866. This was the Upward battery, in which a gas is used electrolytically instead of a liquid, thus dispensing with the use in the cells of acids and depolarising solutions. The battery consists of glazed earthenware cells, divided into compartments, containing ordinary carbon plates surrounded by crushed carbon. These divisions alternate with chambers in which ordinary commercial zinc is placed in blocks. The chambers are filled with plain water, and the compartments containing the carbons are permanently closed with cement. Electricity is generated by chlorine gas, which is admitted to the closed chambers, and circulates from cell to cell, giving the high electromotive force of 2·1 volts, and maintaining a constant current of electricity without the use of a depolariser or any acid or chemicals in the cells. All the attention which the battery requires is the addition of a little water about once a week, and the renewal of the zinc about every six months. The manufacture of the chlorine gas (which is non-explosive under any circumstances) is very simple. The apparatus consists of an earthenware pan, B (Fig. 1), containing manganese, a jar, A, for the hydrochloric acid, and some ordinary drain pipes, D, cemented together for holding the gas. Once in twenty-four hours a small supply of acid is admitted on the manganese by turning a tap for a minute or two, a gauge on the jar A marking when the required quantity has been admitted, the acid being neither seen nor handled. F is a clockwork switch. Gas is then produced, the battery working on quite automatically as long as there is gas, and the making of gas only taking place when the gasholders are empty. The presence of the gas, which is of a yellow colour, is indicated by glass globes fixed upon the holder connections. The replenishing of the acid jar depends upon its size, the ordinary jars holding sufficient for fourteen days' consumption, the manganese being exhausted in about that time. The current when generated, is stored in the accumulators, E, which provide for the lighting of the lamps, with absolute steadiness and constancy at all times. The current can also be used for driving small machines, and for other useful purposes.

The author recently inspected an installation at Messrs. Woodhouse & Rawson's, which is in use for lighting the offices. It is equal to a supply of 700 Watt hours of current, or, put in other words, is capable of driving twenty-four glow lamps of 10

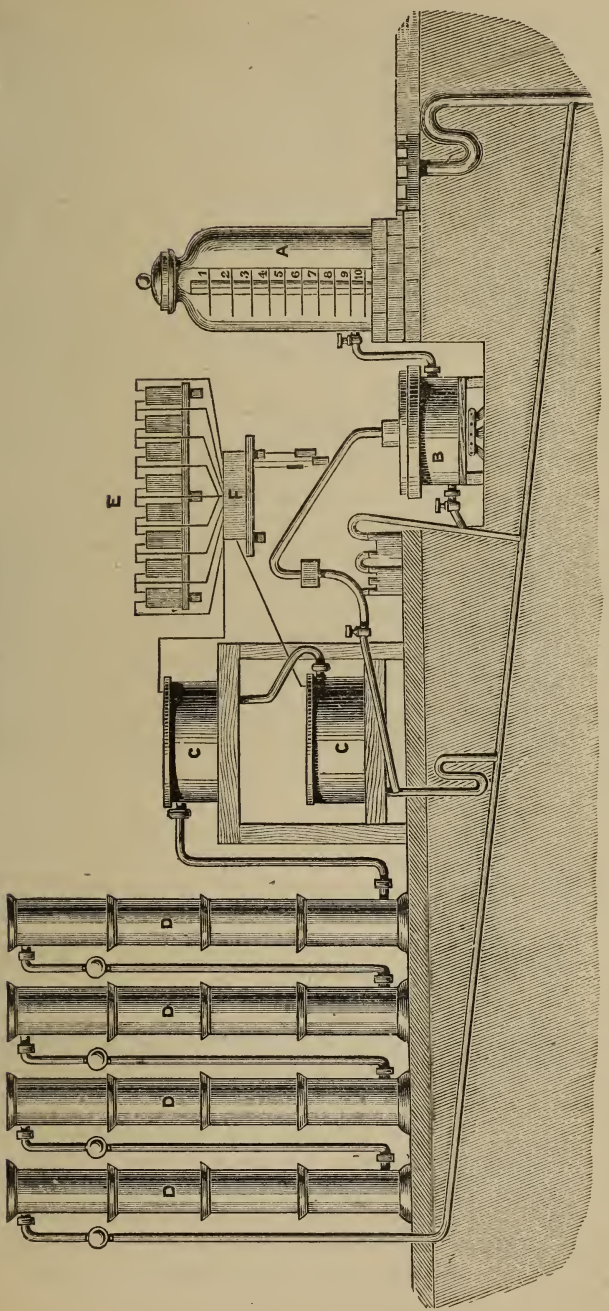


Fig. 1.

The Upward Battery.

candle-power each. The arrangement is slightly different from that shown in the illustration (Fig. 1), which occupies a space of 12 feet by 4 feet by 9 feet high. The plant at Messrs. Woodhouse & Rawson's is placed in a recess in the vaults of the building measuring about 5 feet wide by 6 feet deep and 8 feet high, the gasholders being sunk a foot into the ground, and the accumulators and switch occupying two small shelves in front of the main plant. As a matter of fact, the plant can be placed anywhere—in a cellar, shed, or on the roof—being unaffected by frost, and occupying but a very small space. It will be seen that the apparatus is simple in construction. It, moreover, requires no special skill in management, and is not likely to get out of order. Its further advantages are that it works almost automatically, is noiseless, free from obnoxious fumes, and appears to give no trouble in working. It is stated that the working cost was formerly equal to that of gas at 8s. per thousand; but that it is now much less, owing to some improvements recently introduced into the generating apparatus by Mr. Upward. Dr. Oliver Lodge, of University College, Liverpool, had an Upward battery at work in his laboratory for several months, and he reported very exhaustively and, at the same time, very favourably upon it. The gist of his report is that nearly all the defects of other batteries are absent from it, and he concludes by congratulating Mr. Upward upon the energy and perseverance with which he has tackled and overcome one difficulty after another, and has so developed from a somewhat unpromising beginning a really practical and successful primary battery,—and we here may well unite in these congratulations.

The "Regent" Battery.

The "Regent" battery was brought out in August 1886, with the object of overcoming polarisation, that is, the collection of hydrogen gas on the negative element, and local action, which is produced by irregularity in the composition of the positive element, some parts of which are more highly positive than others, so that local currents are set up, thereby consuming the metal and exhausting the battery. This was a two-fluid battery, and consisted of an outer cell of porcelain, and an inner cell of porous clay, rendered highly conductive by a special process. The inventor claimed to be able to reduce the electrical resistance of the porous septum without at the same time increasing its porosity to liquids, thus limiting the diffusion, whilst reducing the internal resistance. The active or positive element of the battery was an alloy, consisting principally of zinc, so treated that repeated amalgamation was obviated. The plate remained

perfectly bright during consumption, and economy of working by the absence of local action was claimed for it. The other element of the battery was a carbon plate immersed in an oxidising solution, which was said to combine cheapness with constancy of action and almost complete freedom from fumes. It was claimed for the "Regent" battery that, with the greatest simplicity of structure, it surpassed other similarly simple batteries in constancy of electro-motive force, and in cheapness of operation. At the demonstration a "Regent" miner's electric lamp was exhibited, the total weight of which when fully charged was 2 lb. 11 oz., and the light was more intense than that of the ordinary Davy lamp. The cost of domestic lighting was stated to be somewhat higher than that of gas. The author has recently endeavoured to discover the whereabouts of this battery, but without success. It is noteworthy as being one of the first to be utilised for the purpose of mining lamps.

The Pollak Battery.

In October 1886 Messrs. G. Binswanger & Co. (now the General Electric Apparatus Company) introduced a primary battery which was intended, not so much to supply a constant light as for use where an immediate, convenient, and safe light is required for short periods. This was the Pollak battery, each cell of which consists of a glass jar, at the bottom of which is the zinc electrode. The other electrode is carbon, made by Mr. Pollak's process, which ensures great porosity, a large surface, and, at the same time, good conductivity. The lower part of the carbon is plated with copper, or in some cases a small piece of copper wire is suspended in the fluid and connected to the carbon. The zinc of the cells for lighting purposes is covered with sand, and the exciting solution is sal-ammoniac dissolved in water. When thus charged, the action of the battery is twofold. First a local action is set up between the carbon and copper, which causes the reduction of part of the charging fluid and produces combinations of copper. In the case of sal-ammoniac, chloride of copper is produced, colouring the fluid blue and forming the depolariser of the battery. When the outer circuit is closed, the action is that of a carbon, zinc, sal-ammoniac battery, the nascent hydrogen reduces the copper chloride to copper, which is again transformed into copper chloride. Thus the battery constantly forms its own depolariser, i. e. it recharges itself, and therefore such a battery should be one of the most constant known. As will be readily understood, this battery depends largely on gravity, to prevent both local action on the zinc and capillary

attraction; it is therefore essential that the quantity of copper solution should be regulated, and also that the cells should not be moved or shaken. The application of this light to various purposes was exemplified upon the author's inspection, and the battery appeared well adapted for furnishing an immediate and safe intermittent light for short periods, as well as for constant lighting with small glow lamps. By the kindness of Mr. Binswanger, the author is able to place a Pollak cell and a glow lamp upon the table more as a matter of history than anything else, for, with a creditable frankness, Mr. Binswanger informed the author that in practical use the battery was found wanting. The E.M.F. proved to be so small and the resistance increased so considerably with a number of cells that it had to be given up. Still, as a novel and an ingenious primary battery, it had its merits.

The "Union" Battery.

At the close of last year the "Union" battery was brought into public notice, and its working was shown to the author. This is not a primary battery in the strict sense of the term, although it is claimed that it is so to a certain extent. The installation which the author inspected consisted of a battery of twenty cells which provided the current for sixteen Woodhouse & Rawson glow lamps of 12 candle-power each, an excellent light being given. Each cell in this battery is contained in a wood casing measuring 11 inches long by 6 inches wide and 7 inches deep. The whole weighs 20 lb., and is said to have a capacity of 115 ampère-hours. Each cell contains 6 anodes and 7 cathodes immersed in a solution of sulphuric acid. The negative plates are specially prepared, and are set into a very hard and durable substance, possessing great porosity and conductivity. They will not only bear transport, but can be stored dry for use at any time. The conductor is so protected as to prevent its oxidation, thus avoiding loss of capacity by the buckling of the electrodes, and the active material cannot become detached or disintegrated. The cathode is spongy lead. The plates are therefore removed from the cells when exhausted, charged from a dynamo, and replaced for use. In these batteries there is said to be no waste of power by local action and consumption of expensive material. The *modus operandi* is to charge the plates at the works, and to deliver them to consumers, who use them until they are exhausted, and then send them to be recharged. By favour of the Union Electrical Power and Light Company the author is able to illustrate this system by a battery and glow lamps driven from it.

The "Eclipse" Battery.

The "Eclipse" primary battery, which is the invention of Mr. Henry I. Harris, was brought out in June last. It is a portable battery, and consists of a series of cells made of vulcanite and filled with a solution of sulphuric acid, in which is a plate of zinc as a positive. Within the vulcanite cell is a porous cell, charged with a solution of nitrate of soda, in which is the negative element—a carbon pencil. The elements are properly connected up, and the whole form a battery which produces a bright steady glow light, suitable for domestic illumination and for miniug lamps. This latter adaptation appears to be very successful, a 2½ candle-power glow lamp giving an excellent light for twelve hours, at a stated cost of one penny. Referring to this lamp, Dr. Sylvanus Thompson states that the battery will run for thirteen hours without being re-charged. The "Eclipse" battery is said to be very low in price, and to cost only 2*d.* to charge, the charge lasting for twenty-four hours. The battery has been tried by the Great Western Railway Company, and is reported to have given such satisfaction that an express train is to be fitted with lamps on further trial, in accordance with instructions received from Mr. Spagnoletti, the electrical engineer to the company. The lamps have also been in satisfactory use on twenty omnibuses belonging to the London Road Car Company, for two months. Through the kindness of the "Eclipse" battery company, Mr. Harris' invention is illustrated by a table lamp, an omnibus lamp and a miner's safety lamp, which are on the table. The author may mention that the safety lamp was exhibited in the committee-room of the House of Commons during the last three weeks of the late session, while the Coal Mines Regulation Bill was being discussed, and was inspected and approved of by a large number of gentlemen practically interested in coal-mining.

The Newton Battery.

About the same time that the "Eclipse" battery was introduced to public notice, the Newton primary battery was also brought out, and was inspected by the author. Since that time the disposition of the elements has been altered by its inventor, Mr. Charles M. Newton, and sundry other modifications have been introduced by him. In this battery the negative plate is of iron, the positive is zinc, the depolariser a plate of oxide of lead, and the exciting fluid a caustic alkali. Each cell of the original battery consisted of an outer case of

iron forming the negative plate of the cell. On the bottom of this, the depolarising material was spread. Above the latter

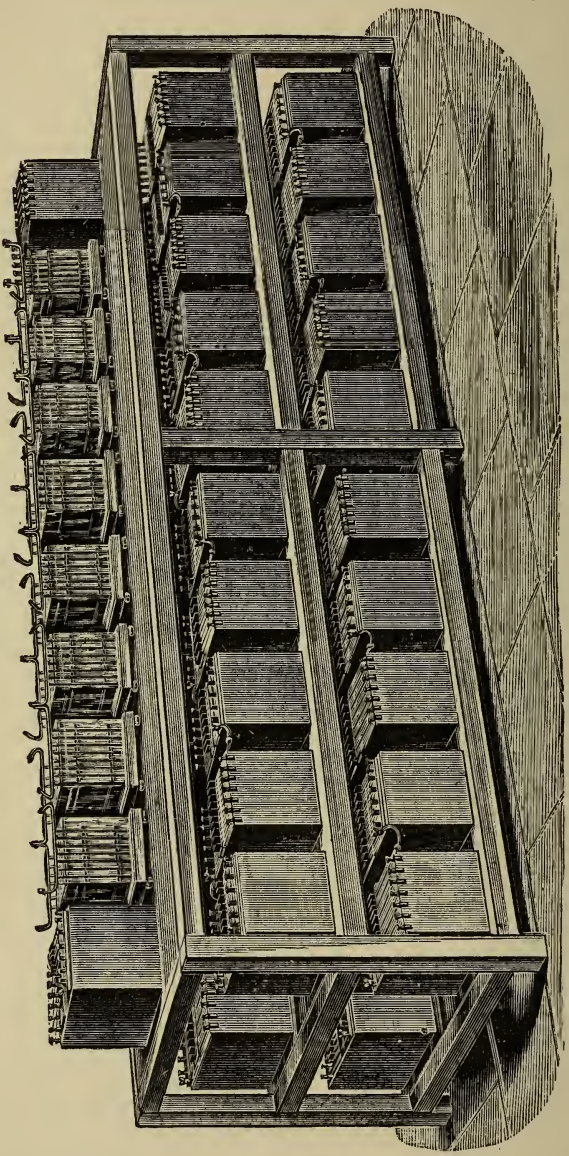


FIG. 2. THE NEWTON BATTERY.

was placed a diaphragm of parchment paper turned up at the edges, so as to divide the cell into an inner and an outer com-

partment, and at the top, resting on glass insulators at the four corners of the cell, the zinc positive plate was laid horizontally. The alkaline solution was then poured into both compartments, and the cell was ready for use. Binding screws were, of course, attached to the two plates, and that on the zinc was protected at the surface of the liquid. This battery has been tried and satisfactorily reported upon by Dr. R. M. Walmsley, F.C.S., who stated that a brilliant and steady light was obtainable for 120 hours without attention. He also stated that the local action was practically negligeable. The author saw seven cells supplying a current to six Shippey Brothers' glow lamps of 10 candle-power each, through seven E.P.S. accumulators. There was no smell whatever arising from the battery, which was due to the absence of acids.

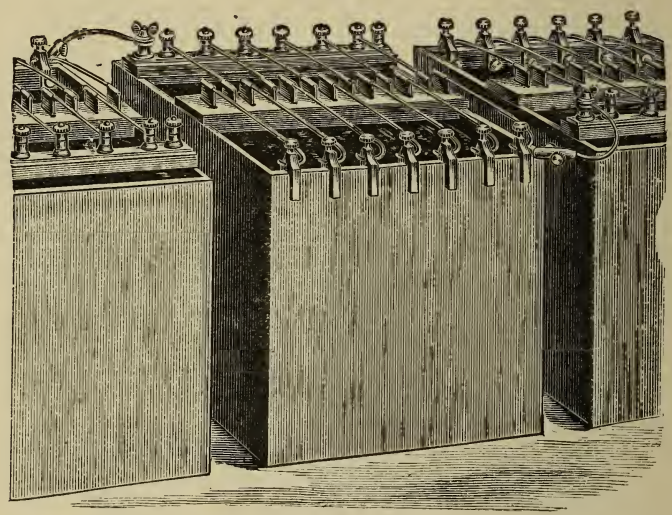
In the improved form of battery which is being brought out by the New Electric Light Syndicate, the electrodes are zinc and iron. The cell, which is of iron, contains alternate vertical plates of these metals, the latter having attached to their surfaces the depolarising plates made of oxide of lead. The exciting fluid with which the cell is filled is a solution of caustic alkali. At starting the electromotive force is stated to be 0·69 volt per cell, which, after 130 hours' continuous run at work, only falls to 0·61 volt, and during the same period the current will merely decline about 13 per cent., and is perfectly steady for the first fifty hours. These statements are given on the authority of Dr. Walmsley. When necessary, the battery is recharged, the spent materials being taken away to be regenerated, and the depolarising plates reoxidised, while the solution is, by a special process, separated from the dissolved zinc. The solution is reserved for further use, and the zinc is converted into a sulphide for use in paint-making.

The chemical action which takes place in the Newton battery has been reported by Mr. Harold Senier, F.C.S., to be as follows :—"The solution of caustic soda gradually dissolves the zinc forming zinc oxide, which is again dissolved in the solution, and at the same time hydrogen is set free. The free hydrogen is given off from the surface of the iron, and, while in the nascent condition, robs the lead oxide of its oxygen, with which it forms water, and so prevents the battery polarising. The depolarising action is the only part played by the lead oxide. By this action the litharge is reduced to the form of black sub-oxide and a portion to the metallic state. The iron is quite unacted upon. The zinc is dissolved to the extent of one-third its original weight. The solution of caustic soda, except that it contains a certain proportion of oxide of zinc in solution appears practically unaltered."

With medium and small installations accumulators are used, and the current is utilised in glow lamps which have been specially designed for the Newton battery. The prime cost of a battery for supplying a current to 50 lamps of 10 candle-power each, with a current of 40 ampères and an E.M.F. of 15 volts, is put at 90*l.* 9*s.*, and its maintenance for 130 hours at 4*l.* 7*s.*, which is equal to 1*s.* 9*d.* per lamp for 130 hours light.

The Newton battery is illustrated in figs. 2 and 3, fig. 2 showing a complete battery of forty-two primary cells, together with eight accumulators, which are arranged on the top of the framework. By starting with nine of the cells, the accumula-

Fig. 3.



tors are charged at an E.M.F. of five volts, and the current is regulated by means of an automatic switch, the remaining cells being gradually added as the potential falls. Fig. 3 is an enlarged view, showing the details of the cell.

The D'Humy Battery.

The next battery for notice in the order of its appearance before the public is that of Mr. P. R. d'Humy, which was brought out in August last. In this battery, which is known as the water primary battery, the positive element is iron in the form of a grid, so that a large surface of metal is exposed within a small compass. The negative element is carbon, and is immersed in nitric acid, the positive element being immersed in water. The cell is divided up into compart-

ments by porous diaphragms, and the acid percolating through the diaphragms permeates and acidulates the water in which the iron electrodes are placed. The installation inspected by the author represents on a small scale a central station, for Mr. d'Humy proposes to apply his system to central lighting. It comprises a battery of twenty cells, each measuring 2 feet long by 1 foot wide and 1 foot deep. The battery occupies a floor space of about 11 feet by 5 feet, and the current produced is stored in forty accumulators specially designed by Mr. d'Humy. Each accumulator is about half the size of a cell. This battery is stated to be equal to 35 volts and 40 ampères, giving 3500 candle-power of arc light and 1000 candle-power of glow light, divided into 10 candle-power lamps. According to a report from Mr. F. J. Varley, these cells show a higher available electromotive efficiency, as compared to the internal resistance of the cell, than any hitherto known constant battery. Another special feature of this installation is Mr. d'Humy's system of subdivision of the current, by which he shows that lights of various candle-power can be given on the same circuit. By using a different potential of lamp on the same wire, he lights up successively glow lamps varying from 3 candle-power to 1000 candle-power, and from 1 candle-power from 3 volts to 1000 candle-power divided from 3 volts to 100 volts. By simply turning a switch, Mr. d'Humy sends the current into a lamp of 100 volts (giving a 1000-candle-power glow light) and at the same time, and by the same wire, another current into a 50-candle-power glow lamp. He also shows a meter for controlling the light consumed per minute, per hour, or for any number of hours.

With regard to the cost of maintenance of this battery, according to a report by Messrs. Gooch and Varley, 1 kilogramme (2·2 lb.) of nitric acid consumed in the water battery —and costing, roughly, 4*d.*—produces a light of 366 candle-power for one hour. One lamp of 10 candle-power, therefore, will cost rather less than half a farthing per hour. For generating the current on the premises, Mr. d'Humy has devised a small battery enclosed in a neat cabinet 5 feet high by 3 feet wide and 2 feet deep. The lower portion contains thirty-two cells, the positive element here being a new alloy, invented by Mr. d'Humy. The plates can be raised out of their solutions, and the battery thus kept at rest when light is not required. There is also a simple arrangement for discharging and replenishing the cells. This battery is stated to be equal to the supply of ten glow lamps of 16 candle-power each, and the cost of lighting is put at about 10 or 15 per cent. above that of gas, light for light. The water battery certainly constitutes a

departure in primary battery practice, and by the light of Mr. d'Humy's installation the invention appears to possess points of ingenuity and merit. It has, however, one drawback in the smell emitted by the nitric acid.

The Friedlaender Battery.

A marked improvement has recently been made in the semi-fluid bichromate battery by Mr. Albert Friedlaender, of Berlin, who took advantage of the circumstance that chromic acid is now manufactured by a new process at a price at which it can be used for this purpose. Chromic acid can now be purchased for from 9*d.* to 1*s.* per lb., whereas it formerly cost from 4*s.* to 5*s.* per lb. In the ordinary bichromate battery the depolariser is a solution of either bichromate of potash or bichromate of soda, in which the carbon and the zinc elements are immersed. These batteries are found to clog, owing to the depolariser having a base, but this objection does not exist with chromic acid. Another important advantage is that chromic acid is much more soluble in water than bichromate of potash, and thereby a much more powerful depolariser can be used in a small cell. The Friedlaender battery has several good features in its mechanical arrangement. It is a small battery, and, with a lamp attached to it, forms a useful and convenient portable lamp, one of which is exhibited on the table. It consists of an outer case of ebonite 8 inches high by 5 inches square in plan. The battery is divided vertically into five cells, and the elements —which are zinc and carbon strips—are arranged in five pairs, and are attached to a small horizontal spindle placed at the back of the battery near the top. One end of this spindle is fitted with a worm-wheel motion, actuated from a thumb-screw on the outside. The depolariser is a solution of chromic acid, the acid being supplied as a powder and dissolved in water. The level of the liquid is kept below the spindle to which the elements are attached, and when the battery is not in use, these latter are maintained in a horizontal position clear of the solution. To put the battery in action the thumbscrew is turned and the elements are gradually immersed in the depolariser. Two advantages result from this arrangement; in the first place, waste is prevented while the battery is out of action, and, in the second, the gradual immersion enables the current to be regulated, and the light graduated and set at any point, from a glimmer to the full capacity of the battery. The zinc and carbon strips are attached to the spindle by set-screws, so that the renewal of the zinc can be easily effected in a minute or two. The lamps used are Swan glow lamps of 8 volts by

FIG. 4.

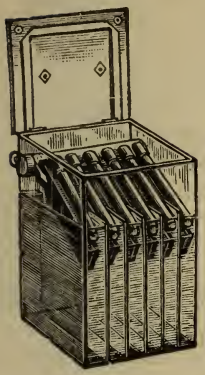


FIG. 5.

FIG. 6.

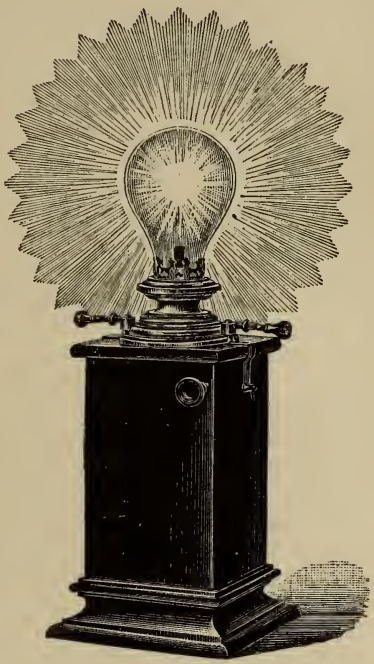
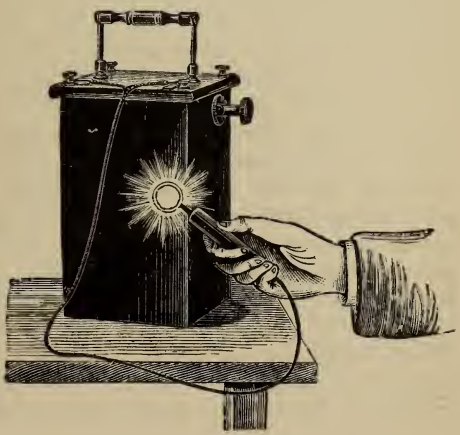


FIG. 7.

FIG. 8.



1 ampère, or between 3 and 4 candle power. The cells are easily emptied of their spent contents and recharged with the solution. Each charge costs between 3*d.* and 4*d.*, and will give a steady current for two and a half to three lamp-hours. The lamp can be attached to the battery either at the front or on the top, or it can be removed and the battery used for surgical or experimental purposes. Referring to the illustrations of the Friedlaender battery, Fig. 4 shows the interior arrangements of the battery; Fig. 5 the battery in action with a lamp at the front; Fig. 6, the battery as arranged with a lamp on the top for domestic use; Fig. 7, the hand battery and lamp with the lamp on the top with an opal glass cap; and Fig. 8, the battery arranged for medical or experimental purposes. These batteries are being introduced into this country by the General Electric Apparatus Company, previously referred to.

The Edison and Swan Safety Lamp.

Seeing the important part the electric light in one form or other appears destined to play in connection with the mining safety lamp, the author intended introducing that subject into his paper. Having, however, learned that Sir Frederick Abel is about to read a paper on that special subject, the author will only notice it in passing, without wishing to invite discussion upon it. This he must necessarily do, inasmuch as the "Eclipse" primary battery, already noticed, has been adapted to a safety lamp, and has been brought under public notice in a marked manner. There is, however, another miner's lamp which has also been prominently before the public of late, and this is the Edison and Swan Company's safety lamp. By the kindness of the company, two of these lamps are on the table. The battery here, however, is not a primary, but a secondary battery, and the lamp consists of four small accumulators enclosed in a teak box, strengthened with metal bands, and having a small glow lamp mounted on the side of the case and protected by a strong glass. The case is fitted with a hinged lid, secured by a cross-bar, fastened with a safety nut, and having a swivel handle. The lamp measures 7 inches by $4\frac{1}{2}$ inches, and weighs, ready for use, 6 lb. 13 oz. The lamp is opened by unscrewing the safety nut, and raising the hinged lid, when the battery can be withdrawn. The four cells composing the battery are joined in series, the terminals being brought down the sides of the battery in the form of two contact plates, which, when the battery is put into the case, come in contact with two corresponding plates in the case, and thus convey the current to the lamp. One charge of the battery will last from

ten to twelve hours. The battery is recharged from a dynamo machine. With a sufficiently powerful machine several hundreds may be charged at once. The lamp can also be fitted with a fire-damp indicator, which, it is stated, will indicate a percentage of fire-damp or choke-damp as low as 0·1 per cent.

Conclusions.

The author has now described sixteen primary batteries, being all that have come under his notice, and has given such particulars concerning them as the limitation he has prescribed for the subject will permit. It might be expected that he should now proceed to analyse the various systems, and to pronounce an opinion upon their relative merits. Two things stand in the way of this. In the first place, the present paper has been prepared at short notice to meet an emergency, and was only commenced three weeks since, so that there has been neither time nor opportunity for such a careful examination to be made as should entitle the conclusions drawn from it to respect. In the next place, the author conceives that no single person should undertake the task of examination. Electric lighting is still but in its infancy, and no system ought to be either condemned or approved without very careful and exhaustive trial. To this end the various batteries should be placed unreservedly in the hands of three disinterested professional men—an electrician, a chemist, and an engineer, for all three professions are represented in every primary battery system. The author is not quite sure that the various patents should not undergo a preliminary investigation by a patent agent. We are, however, fortunate in having among us to-night several eminent electricians, and from these masters of the science, as well as from some of the inventors of the batteries, we may hope to hear something more respecting the practical value of these batteries than the author has been able to give in his paper. Broadly and generally speaking, it appears to him that it has yet to be proved that any one of the batteries could be applied to the partial illumination of moderate-sized houses—for that is what is really wanted—with commercial success. For large establishments there is evidence based on practical use that the Upward, the Holmes, and the Lalande batteries are suitable, that is, where cost does not stand in the way. It has not, however, been shown to the satisfaction of the author that any one of them can be used economically for lighting the principal rooms in more modest residences; in a word, for the general public. The author has been met by some with the statement that the general public

could, at the present time, be supplied with electric lighting by primary batteries as cheaply as they are with gas, but that, until clients from the wealthier classes, to whom expense is not an object, have been exhausted, prices will not and should not be lowered. The author conceives this course to be a mistake, for the process of exhaustion will be slow. Oil lamps and candles are still used in the principal rooms in numbers of mansions, and in the residences of the upper classes, and will continue to be so used owing to their effective appearance as works of art—as many of them are—and to the greater purity of the air resulting from the combustion of oil as compared with that of gas.

To popularise the electric light—and to popularise it is the only way to make it pay—it must be cheap and efficient. By cheapness is to be understood either a small first cost and a correspondingly small cost for maintenance, as in the case of a battery placed in the house, or a moderate charge for the supply of the current, as in the case of a central distributing station. The lamps must be adaptable to the present gas fittings, and the cost of the light must be but little in excess of that of the gas of the district. The author does not for one moment ignore the advantages of the electric light from a hygienic or a domestic point of view; he is but too familiar with the unpleasant atmosphere which results from burning gas even with the best burners and in ventilated rooms, although his lucubrations are generally carried on by the aid of an oil lamp. The general public, however, will in the main continue to use the present ordinary methods of illumination, however defective they may know them to be, rather than adopt any new system which entails extra cost, however satisfied they may be that positive advantages are to be gained from it. Men will weigh the extra cost against the extra advantages, and in the majority of cases the former will be allowed to outweigh the latter.

That there are merits in many of the primary systems described—that is, those which have survived their introduction to the public—there can be no doubt, some possessing points which are absent in others. And be it remembered that the list of primary batteries is not exhausted by those described by the author. It might therefore be desirable that a fusion of interests should be effected, and that a committee of independent electricians, chemists, engineers, and sound commercial men be formed to practically test each battery to destruction. Out of the results might be formulated a system which would meet all the requirements of the general public, and which might eventually be the means of saving the proprietors of those

systems which fell short of the mark from absolute loss. The results of this method of applying the doctrine of the survival of the fittest would, perhaps, press the least inconveniently upon those doomed to suffer by this inexorable law. Of course, the author can quite understand every inventor present assuring himself that he is not going to be an absolute loser, but that he is going in to win. The author can only sincerely hope it may be so. Every battery represents a considerable expenditure of time, money, and anxious thought, and every inventor deserves, if he does not achieve, ultimate success.

In conclusion, the author desires to express his thanks to those gentlemen who have been good enough to lend him their batteries, and to fit up the present installations of electrical lighting to illustrate his paper, and whose names have already been mentioned.

Discussion.

Mr. W. H. Preece said that he must confess that he was to a certain extent an opponent to the introduction of primary batteries for the distribution of electricity to houses. Few persons had had more experience of their use than himself, and he believed that any attempt, with our present knowledge, to utilise them for general lighting must end in disaster. At the same time there were many purposes to which they could be applied with advantage. The sixteen or eighteen batteries which Mr. Nursey had described were but a small instalment of the total number of primary batteries which had been thrust upon the public during the last few years. Many of these batteries were surrounded with a halo of mystery. The depolarising agent and the exciting solution were kept secret, and the result was that all that was known about the batteries was the very extravagant statements which appeared in prospectuses and descriptions. One, however, of the primary batteries described in the paper, that of Mr. Upward, was very promising, and he certainly thought would have made a stir. He could hardly understand why it had not been more practically applied for lighting purposes.

He would like to ask whether there was a gentleman in the room who could rise and give them the practical results and cost of twelve months' working of any primary battery. In fact he (Mr. Preece) would be satisfied to hear an account of three months' successful working. Practical men wanted actual figures, showing the expense of using primary batteries. He noticed that in the estimates given in the paper there was an omission of one most serious item of expenditure, and that was the labour required in cleaning and charging the batteries. His

experience was that the cost of the metals and the acids was a fraction only of the real cost, which was that of the labour in working the batteries. As to the utilisation of the waste products formed in the batteries, the Post Office had some four or five hundred thousand batteries in use, the bye-products of which were very weighty, but had never repaid the cost of collection. The field in which primary batteries would make a stir in the world was not the lighting of houses, but the supplying of safety lamps for miners. There was no greater want of the age than a handy, portable, and convenient light, which miners could use with ease to themselves and safety to their fellow-workmen. No doubt the public would know more upon this subject when Sir Frederick Abel read his forthcoming paper on the subject at the Institution of Civil Engineers. Two thousand six hundred lamps had been ordered for a colliery in the neighbourhood of Cardiff. The most valuable form of secondary battery mentioned in the paper was the "Union." This was one which ought to have come to the front, as the author had observed. He was a little surprised that Mr. Nursey had not described the Schanschieff battery, which he (Mr. Preece) had been experimenting with during the past twelve months. It was an extremely simple one, and consisted of zinc and carbon in a very densely saturated solution of sulphate of mercury. The mercury itself was dissolved in hot sulphuric acid, the result being a density of about 1·4, and the consequence was that all depolarising agents were thereby got rid of. The battery had a high electromotive force, viz. 1·4 volt, and a very low internal resistance. The "Eclipse" battery seemed to give a very nice steady light, but he should like some one to explain the difference between that and the "Holmes" battery. The only difference seemed to be in size.

Mr. Octavius March accepted Mr. Preece's challenge to give an account of the practical working of a primary battery. Some two years ago he put up an installation of between 30 and 40 incandescent lamps, with the Holmes battery, at a gentleman's house in Leicestershire. That installation had worked with perfect satisfaction ever since, and was running at the present time. Of course the cost of light from primary batteries must be more than the cost of gas. As Mr. Nursey said in his paper, the cost was something like double that of gas at 3*s.* or 3*s.* 6*d.* a thousand. Mr. Yarrow had had an installation running with success for about three years, and the late Sir Francis Bolton had had one for about two years, which was still maintained by Lady Bolton. He hoped sufficient evidence had been given that the primary battery was not so entirely a failure for illuminating purposes as Mr. Preece seemed to think. Of course much was yet to be desired in the question

of cost; he thought it was too sanguine to expect light from primary batteries at a less price than gas; but people who were prepared to pay a reasonable price for the convenience, cleanliness, and healthiness of the electric light, could obtain it by means of a good primary battery, such as the one he represented.

Mr. CLIFTON, representing the "Eclipse" Company, said that he was happy to be present and to hear the remarks that Mr. Preece had made concerning the "Eclipse" battery *v.* the Holmes and Burke. He (Mr. Clifton) was years ago employed in connection with the primary batteries which at that time belonged to Holmes and Burke, and the difference between theirs and the "Eclipse" was very great. The "Eclipse" consumed about 50 per cent. less nitrate of soda than the Holmes for an equal number of lights. The cost of maintenance of the "Eclipse" was considerably less in every respect, being a penny for a five-candle lamp for nine hours. He believed that the size of the "Eclipse" was only one-fifth of that of the Holmes, the space occupied by the latter battery, suitable for ten five-candle lamps, being about 10 feet by 1 foot 6 inches by 1 foot, thus necessitating a shelf which would be extremely inconvenient in an ordinary middle-sized kitchen. In first cost, also, the "Eclipse" had a considerable advantage. The manipulation of the "Eclipse" was very easy, in fact, any ordinary servant could attend to the battery very well. In it the two substances used were not mixed outside the cell. The nitrate of soda was used in its crystalline state, and just as the lights required it. Mr. Clifton also pointed out the distinction between the incandescent state of a five-candle lamp of the Eclipse type and that of the Holmes and Burke. The miners' lamp made by the "Eclipse" Company had been approved at the House of Commons, and as its cost was only 14*s.* it came within the reach of every miner. The miners' lamp made by the Swan Company cost about 50*s.*, and weighed considerably more than the "Eclipse."

Mr. J. J. WALSH said that he had used the "Eclipse" lights on the Road Car Company's buses for over six months, and on the South-Western Railway for over eight months. One of the "Eclipse" lamps now exhibited on the table was that which had been adapted for the use of miners.

Mr. O. C. D. ROSS said that he was the inventor of one of the batteries mentioned by the author. This was a zinc and carbon battery. The only "mystery" in connection with it was that he had occasionally called his oxidising agent "Eureka," but he was quite prepared to explain what the liquid was. It was a very economical one, being composed of three parts muriatic acid, three parts water, and one part of any strong oxidising

agent. He generally used a peculiar kind of fuming nitric acid, but had sometimes used nitrate of soda, mixed with the muriatic acid. Mr. Holmes used nitrate of soda and sulphuric acid, but he (Mr. Ross) did not think that this was quite so good for a constant current as the muriatic acid which he employed. He had had experience of lighting large houses by means of primary batteries. There was no real difficulty in the matter beyond the mechanical arrangements. These should be such as to allow servants to manage them easily. If a battery consisted of a large number of cells which required to be separately filled and emptied, it was difficult to find domestic servants who could attend to it. His battery was constructed so that he could draw off the liquid from a dozen cells at one time and refill them by the same motion. He had now improved upon that, and it would surprise, perhaps, Mr. Preece as much as any one else, to learn that he had found a way of putting the cells together into a reservoir of liquid, so that they fed themselves. This was done by means of a very simple contrivance; the battery occupied a smaller space, and altogether was such as any servant might be trusted with. One point in connection with batteries required something more than a domestic servant's attention, and that was the keeping of the elements in good order. It was a very difficult thing to keep the carbons in such a state that they would not deteriorate, because if the carbon plate was of a sufficient size to allow a large number of lights, say from twenty to forty, to be lighted, there were necessarily a number of parts, which had to be connected together with metal, and if that metal was affected by the acids, the carbons were very soon unfit for use. The carbon plates which he used were made by combining together a number of rods, which were the waste rods from the manufacture of carbons for arc lighting. Primary batteries cost much less at first starting than any form of dynamo or accumulator, and they were to a very large extent adaptable to fairly well-kept houses. He did not, however, think that it was possible to obtain the light quite as cheaply as gas, although there was not much difference.

Mr. Hugh Fergusson, referring to Mr. Preece's challenge, said that he was interested in the Lalande battery, and he could state that during the year 1886 they ran altogether about a thousand lights at the offices of Messrs. Borthwick, Wark & Co., Copthall Court, and Messrs. Offley, Forrester & Co., of Mark Lane, and they also supplied the town house of Lord Onslow and the town and country houses of Lord Wenlock, and many others in London and the country. Tests which appeared to be exhaustive had been made by Professor Tait of Edinburgh, Professors Jamieson and Dittmar of Glasgow, and other scientific

men, and those gentlemen had reported on the subject. Their reports agreed with those of French scientists, such as d'Arsonval, Regnier, Schenk, and Abdauk, in the statement that the Lalande battery was a very constant one. The light had been approved, and the only doubt expressed was as to getting back the zinc. That had been done. The zinc had been recovered in the metallic form, and he would shortly send a sample of it to Mr. Preece. He (Mr. Fergusson) hoped to prove that there was a considerable advantage in using the Lalande primary battery, and that the residual products of the battery could be utilised and sold at a profit.

Mr. A. R. Upward said that during the last few months the Upward battery had been supplied to the Government of Valparaiso, and had been in use at the Manchester Exhibition, at University College, Liverpool, at a brewery at Ely, and at offices in Queen Victoria Street, and also in Cologne. They began with the type shown in Fig. 1, which consisted of a group of small cells connected in a series, and a suction apparatus was used to draw the gas through the cells. Although this arrangement worked thoroughly well, he simplified and cheapened the apparatus by using two or three cells only, of large dimensions, connected to the secondary battery through a clockwork drum switch. One of the chief objects of the new type was to avoid the large number of chlorine connections which were required when a large number of small cells was used. The present form of battery had been on the market a few months only, and he considered that on the whole they had made a very fair start.

The Earl of Galloway said that he and his co-directors of the Elieson Electric Company felt honoured by being invited to the meeting. He could not pretend that he had studied the question of primary batteries at all. It was in connection with secondary batteries that his company hoped to make some show in the world. Mr. Elieson had been led to consider whether he could not invent an accumulator which could be really depended upon for locomotive purposes. The Company had an opportunity of making a small display of Mr. Elieson's accumulator on the 14th October, by running locomotives on the Stratford Tramway from Stratford to Manor Park. Their next demonstration was at the docks, where they showed the accumulator in connection with a little vessel, which some months before had been christened *The Countess*. They afterwards had the satisfaction of hearing both from Dr. Thompson and Professor Perry that they were perfectly satisfied that Mr. Elieson had introduced an appliance in electricity which, in the future, would be recognised by the world at large. Mr. Elieson had already made an improvement upon his original secondary

battery. The first form had succeeded very well, both for locomotive purposes and for lighting, but the cost and weight of the new accumulator were considerably less than those of the original ones.

Mr. G. Binswanger said that he believed that all electricians who had had experience with primary batteries must endorse the remarks of Mr. Preece, that, though such batteries had a certain use, their field was limited. There were exceptions; but, even taking these into account, he held that primary batteries would not do what might be expected from them, though they would supply a light for small portable lamps, and for lamps for mining and medical purposes. Primary batteries were of two kinds—those that used depolarizing acids, and those that used salts as depolarizing agents. When the latter were used the battery could be left standing for a long time without any attention, and the cost of labour, which Mr. Preece had mentioned as the greatest part of the cost of primary batteries, was almost done away with—certainly was much less than in batteries in which salts were not used. But in all batteries which used salts the electro-motive force was very small, and this was the case with the Lalande, and accounts for the comparatively small success of another useful and meritorious battery. He was interested in a small battery which was not very pretentious, but he believed that it would do well what it was intended to do, which was to give a small light for a short time. In this case the inventor, Mr. Friedlaender, had not invented anything very great; in fact, no one had done so with regard to primary batteries. Almost everything in connection with them was foreshadowed thirty years ago, of which any one might convince himself by reading 'Viaudet on Primary Batteries.' The great improvement to be made in connection with such batteries was in their mechanical details. One thing which Mr. Nursey had mentioned as giving the primary battery more chance of success was the reduction of price. Mr. Friedlaender had taken advantage of the reduced price of chromic acid. This substance could now be obtained as cheaply as, or more cheaply than, bichromate of potash. They all knew that chromic acid and nitric acid were great depolarizers, but until recently chromic acid had been too dear for ordinary use. In Mr. Friedlaender's battery the arrangements for lifting the elements out of the fluid were very ingenious. Though he did not claim anything new for Mr. Friedlaender's lamp, he believed that there were great improvements in it, and that for mining purposes and small lighting it would be all that was desired.

Mr. Hearson had attended the meeting for the purpose

of gaining information concerning primary batteries on behalf of Lord Onslow. His lordship had for some time had his house illuminated by means of a primary battery, but at the present time the battery was stopped. Lord Onslow wanted another to replace this one, and he (Mr. Hearson) was commissioned to select a good one. When Lord Onslow set up a battery twelve months ago he did so contrary to his (Mr. Hearson's) wishes, for, like Mr. Preece and another speaker, he believed that all forms of primary batteries were practically useless for electric lighting where more than four or five lights were wanted. It was intended, when the battery was set up, that the bye-products should be collected. He had been waiting for the collection of the products, and for the batteries to be recharged, but it had not taken place, and in the meantime the light had gone out. He was afraid that he should leave the meeting with the impression with which he came to it, that there was nothing ripe at present which he could put into the cellar of Lord Onslow's house in place of the battery which had gone out of use. If anything suitable was pointed out to him he was a customer; but he feared that he should not hear of anything which would compete with coal-gas.

Mr. Desmond G. Fitzgerald, speaking as an electrician who had had more than a quarter of a century's experience of various forms of battery, said that, in common with many other electricians, he had been astounded at many of the statements which had been put forth on behalf of primary batteries. Various batteries of the kind had been disinterred from the limbo of past failures, having been condemned twenty-five or thirty years ago. He must, however, except from those strictures the chlorine battery of Mr. Upward, and the Lalande-Chaperon battery, which had some extraordinary properties. The last-mentioned possessed, perhaps in a higher degree than any other, the capacity for supplying large currents, and was condemned only by its small electro-motive force. As had been said that evening, many of the batteries which had been brought forward were surrounded by a halo of mystery, and various loose and inaccurate statements had been made as to the quantity of materials consumed. He had jotted down certain electro-chemical equivalents, which might be useful. When zinc was used in a battery, they could not consume less (though they might consume more) than 2·02 lb. per horse-power per hour electrical, divided by the electro-motive force of the cell $\left(\frac{2\cdot02 \text{ lb.}}{E}\right)$; if lead were used the quantity would be $\frac{6\cdot38 \text{ lb.}}{E}$; with iron it was $\frac{1\cdot73 \text{ lb.}}{E}$; with

sulphuric acid, $\frac{3{\cdot}02 \text{ lb.}}{E}$; with nitric acid, $\frac{3{\cdot}88 \text{ lb.}}{E}$; with chromic acid, $\frac{2{\cdot}06 \text{ lb.}}{E}$; and with peroxide of lead, $\frac{7{\cdot}36 \text{ lb.}}{E}$. When the electric energy was obtained through the agency of the steam engine, the cost was far less than in the case of a primary battery; and with such a fact staring one in the face, it was scarcely possible to look with any degree of patience on the use of primary batteries, consuming expensive materials, for electric lighting on a large scale. If they were intended for small applications, in which the expense was not a matter of moment, engineers could bear with them; but it was altogether out of the question to suppose for one instant that any of the batteries could be used economically on a large scale in the absence of a system of regeneration by means of the steam engine. He hoped that the figures which he had given would enable the members of the Society to check any statements which required to be brought to the test.

Mr. F. L. Rawson thanked Mr. Preece for the way in which he had mentioned the Upward battery. That battery was worked by his company, who were in a different position from most inventors of primary batteries, who, with all due respect to them, did not usually care what happened to their batteries after they had gone out of their hands. If difficulties occurred with a battery after his company had fixed it, they would have to take it away without being paid. That was the reason that they had not done more with the Upward battery up to the present time. They started working at the battery about four years ago, and with the help of Mr. Upward they had been gradually finding out and remedying the difficulties which arose in the course of practically working with it. That was the only way in which primary batteries could be made successful. They had now several batteries running very satisfactorily. He did not know whether Mr. Stetson was present at the meeting, but that gentleman had come over from America making inquiries about the Upward battery, and after having thoroughly looked into the working of it, he had said, "I am thoroughly satisfied that the thing is practicable. You seem to have got over all difficulties. The only question is what it will cost to work." The question of cost was a very large one, and depended to a great extent upon the cost of the materials used and the ability to utilise the residual products. In the Upward battery they utilised practically the whole of the theoretical value of the zinc, and chlorine was one of the cheapest gases which could be used. They had also reduced the cost of the materials by from 50 to 75 per cent. during the last two years. There was a large demand for

a good battery, and he might state that, in the previous week, they refused a very large order for the Upward battery, because they preferred to wait until they had effected further improvements. They looked forward to another twelve or eighteen months' work before they would get the battery into such a form that they could say that it was fit to take the place of a dynamo and gas engine, for lighting a house with fifty or a hundred lights. There were many places the occupiers of which would be willing to pay three or four times the cost of gas, if they could have the electric light. There were many primary batteries which would do the required work, if the mechanical details were suitable. He quite agreed with Mr. Binswanger that the question of the mechanical details was one of the most important matters in connection with batteries. Persons who purchased electric lamps for use in places such as bank cellars, or in some mines, would not mind paying eight or ten times the cost of gaslight, provided that the mechanical details were such that the battery could be attended to and charged without trouble. His firm had spent many hundreds of pounds in working out the mechanical arrangement of batteries invented by different people. When the batteries had broken down, the failure had generally been a mechanical one. The old form of battery, namely, the Edco, which was exhibited at the Paris Exhibition by the Electro-Dynamic Company of Philadelphia, was still being sold at the present day, simply on account of its mechanical details being fairly well worked out, although the cost of the light which it gave was extremely high in comparison with gas and other illuminants. The Schanschieff battery was one upon which his firm spent a considerable sum of money two or three years ago, and he could thoroughly endorse Mr. Preece's remarks upon it. In conclusion he might say that Mr. Upward had worked out his details, and this battery was certainly one of the most practical batteries in existence at the present time. No doubt something more would be heard of it.

Dr. J. A. Fleming said that certain delusive statements with regard to primary batteries recurred with undiminished freshness. One of these had reference to the sale of waste products. It should be remembered that, if the waste products were brought into the market in abundance, the prices of them would fall. It did not follow, for instance, that because oxide of zinc was now at a certain price it would continue to be sold at that price if it was produced as a bye-product of batteries.

There was a form of primary battery which had not been mentioned by Mr. Nursey, which was very steady in its electromotive force, and could be left for a considerable time, and was always ready for use. Its electro-motive force was 2·2 volts.

He had been very much surprised to read in the *Times* that morning that chromic acid had come into the market as a new product, and that it was preferable in the carbon-zinc battery to the ordinary solution. He believed that chromic acid solution was rapidly deteriorated or deoxydised in the neighbourhood of the carbon, unless there was some arrangement for circulating the fluid, and that would be very troublesome in practice. Five or six times more zinc was consumed by local action than was represented by the current. Mr. Nursey had mentioned in his paper the Swan-Edison lamp for the use of miners, and that lamp had also been referred to by the gentleman who so eloquently represented the "Eclipse" battery. The statements which that last gentleman had made with regard to the Swan-Edison miner's lamp had not been communicated to him by the Swan-Edison Company, but must have been evolved from his own inner consciousness. It might interest those persons who were looking at mining lamps to examine the latest form of such lamp at the close of the meeting. The present lamp was the outcome of the work which had been done by the Swan-Edison Company. It would be found that it had assumed a very practical form. Many points had to be considered in connection with mining lamps, in addition to those of expense and weight.

The PRESIDENT, in closing the meeting at a late hour, requested Mr. Nursey to send his reply in writing to the Secretary.

The following communication was afterwards received from Mr. Nursey in accordance with the wish of the President :—

The general tone of the discussion, as regards myself, has been so in accord with the conclusions at which I arrived in my paper, that it leaves me very little to reply to. Mr. Preece not only endorses my views with respect to the circumscribed use of primary batteries for illuminating purposes, but goes much further, and believes that any attempt to utilise them for general lighting, must end in disaster. I am not prepared to agree with him there, for I do not consider that what has not yet been accomplished, can never be done. Seeing the great advances that have been made of late, and the success that so far has attended those advances, I am not without hope that we may yet have a primary battery embodying the necessary conditions as laid down in my paper. Mr. Preece expresses his surprise that I did not describe the Schanschieff battery. I specifically stated in my paper, that I only described those

batteries which I had had the opportunity of inspecting. The Schanschieff battery not having been seen or heard of by me, up to the time of the reading of my paper, because it had not been brought out publicly, I could not of course describe it. Mr. Preece observes that in my estimates there is an omission of a serious item of expenditure, namely, the cost of labour for cleaning and charging the batteries. I need hardly point out that, at the present stage of primary battery lighting, that item must be for the most part an unknown quantity. In some cases it is not ascertainable, whilst in others, although it is at present known to be considerable, it is believed that it is capable of reduction, and hence it would hardly be fair to give the figures.

Dr. Fleming states that there is a form of battery which I have not described, but he does not say whose battery it is, nor does he describe it, so that our stock of knowledge is not increased on that point. When, however, it is remembered that, as Mr. Preece justly observes, and as is stated in my paper, the sixteen batteries I have described form but a small percentage of the total number that have been brought out within the last few years, it is hardly surprising that I failed to make the acquaintance of a greater number than I have, seeing that I am not an electrical engineer. Anyhow, those I have described are fair representatives of their various types, and a few of them, notably the Upward, are both meritorious and promising. The question of primary battery lighting is young, and is surrounded on all sides by problems of greater or less difficulty, which will have to be solved before any system can come into general use.

December 5th, 1887.

HENRY ROBINSON, PRESIDENT, IN THE CHAIR.

A NEW FORMULA FOR THE FLOW OF WATER IN PIPES AND OPEN CHANNELS.

By EDGAR C. THRUPP.

At the beginning of the present year, the President of this Society, Professor Robinson, published his book on 'Hydraulic Power and Hydraulic Machinery,' and in that book he was good enough to find a place for a new hydraulic formula arrived at by the author. It is at the suggestion of Professor Robinson that this paper has been prepared, to lay before the Society the method by which that formula was obtained and to establish its claim as a substitute for older ones. At the same time the author thought it might be interesting to study the results of experiments with open channels, by reducing them to a formula in a similar manner to that employed to obtain the formula above mentioned, and thus see if any light could be thrown on the subject of flow in pipes by experiments with open channels, and *vice versâ*. The outcome of this investigation has been far more satisfactory than was expected, and has enabled the author to introduce a modification into his published formula, which renders it much more accurate than it was possible to make it with the data to hand about the flow in pipes.

EXPERIMENTS WITH PIPES.

The results of experiments were first reduced to the three functions, diameter, discharge, and cosecant of slope. The slopes and discharges were then plotted to scales sufficiently large to detect differences of at most 1 per cent., generally much less, and curves were sketched through the points so obtained as far as possible. These were connected by lines drawn through the points corresponding to equal velocities. This brought out a difficulty which is seldom mentioned by writers on this subject, namely, the impossibility of determining with absolute accuracy whether two pipes of different diameters have the same roughness.

If the pipes were of the same roughness, the equal velocity lines would be symmetrical curves of parabolic form, rising from the origin. But the result showed an erratic set of lines for pipes which were all described as new cast iron. To draw a curve which should represent an approximation to the truth would be an extremely difficult thing to do, and more difficult to extend. The problem was, however, much simplified by the second stage of the investigation. Instead of plotting the values of S and Q, their logarithms were plotted, the result being that straight or nearly straight lines were obtained for each pipe in place of a discharge curve. This method of investigation was applied by Prof. Osborne Reynolds, with the same object, but he plotted the logarithms of the sines of the slope and of the mean velocity.

These lines are the "logarithmic homologues" of the discharge curves. With some conditions they were found to be inclined at 2 to 1, but at low velocities and with some materials they became steeper, being about 1·7 or 1·8 to 1, and at extremely low velocities they are almost at 1 to 1. (Diagram I. Plate 2.)

These inclinations form a most interesting study. They were originally assumed to be all on a slope of 2 to 1 (which would indicate that the resistance varied as the square of the velocity), but experiments showed a considerable deviation from this position, and the observations of Poiseuille proved that for capillary tubes they were at a slope of 1 to 1 (which showed that in that case the resistance varied directly as the velocity).

The point at which this 1 to 1 slope ends has been observed by Prof. Reynolds, and by the experiments of Darcy in four cases (Nos. 2, 4, 8, and 5), and of James Leslie in one case (No. 13). In none of these cases does the line bend off to a slope of 2 to 1, but has an inclination lying between 1·7 to 1 and 1·8 to 1. Prof. Osborne Reynolds' experiments were made with a view to determine whether the motion of water should be direct or sinuous, and to determine the relation between the velocity and the resistance.* By arranging a glass tube in such a manner as to admit a fine stream of coloured liquid into its centre, while a stream of clear water was flowing through, he was able to observe the conduct of the coloured liquid. He found that at low velocities the coloured liquid formed itself into a perfectly steady band along the centre of the tube, thus proving that the motion can be "direct." He also found, on increasing the velocity, that there was a critical velocity at which the coloured liquid got mixed up with the rest of the

* Phil. Trans., Part III., 1883.

water, and that this velocity was proportional to the viscosity, and inversely proportional to the diameter of the pipe. This he describes as "a critical velocity at which eddies come in."* Prof. Reynolds also made some experiments on the flow of water through lead pipes. In these experiments the loss of pressure was observed by a delicate differential pressure gauge, the two ends of which communicated with two small holes drilled in the lead pipe five feet apart. It was found that at low velocities the resistance was directly proportional to the velocity; but this law only held true up to a certain point, and at this point the liquid in the pressure gauge was observed to become agitated.

Prof. Reynolds says,—"For some little distance after passing the critical velocity, no very simple relations appear to hold between the pressures and the velocities. But by the time the velocity reached $1 \cdot 2 \times v_c$ (critical velocity), the relation became again simple." It was observed also in this case, that the critical velocities were in exact inverse ratio of the diameters of the pipes.

Last year the author carried out some experiments with a $\frac{1}{2}$-inch wrought-iron pipe, with a view to study the law of flow in the neighbourhood of the critical point, and also the effect of changes of temperature. The latter idea he abandoned on the publication of Mr. Mair's excellent experiments on that subject at Messrs. Simpson & Co.'s works. The results obtained with the $\frac{1}{2}$-inch pipe are perhaps worth giving, inasmuch as they completely confirm some of Darcy's results, which were regarded as erratic until Prof. Osborne Reynolds pointed out in 1883 that they were not so, and afford further evidence in contradiction of the theory of Mr. Hamilton Smith, who "hazards the guess" that the critical point is a phantom. The apparatus used by the author was very simple. Plate 1 shows the arrangement. Two small holes were made in the pipe A B at the points C and D exactly 10 feet apart. They were made by filing down the pipe with the corner of a file until a hole about $\frac{1}{20}$th of an inch across appeared; and the roughness produced by filing was smoothed down by working an iron bar backwards and forwards inside the pipe. Joints were made with indiarubber tubes $\frac{1}{4}$ inch diameter, in such a manner as to avoid any projections into the $\frac{1}{2}$-inch pipe, and the tubes were connected to glass funnels $1\frac{3}{4}$ inch diameter, open at the tops to admit pointers to measure the water level. These pointers were adjusted to exactly the same length by filling the pipes with water at rest and making the upper ends of the pointers meet at the same point on the vertical scale, while the lower ends just touched the water surface. When the water in the

* Phil. Trans., Part III., 1883, p. 955.

iron pipe was in motion, the difference of the water levels in the glass funnels gave the loss of head "h" in the length C D. The discharge was measured by means of orifices in the gauge box L, and regulated by taps in the india-rubber tubes at J and K. The gauge box was of wood with a glass front. It was 2 feet high, and 9 inches by $4\frac{1}{2}$ inches inside, and a tin plate was fixed in the bottom in which 7 circular orifices were made, varying from about $\frac{1}{10}$th to $\frac{1}{3}$rd of an inch in diameter. A scale divided to $\frac{1}{10}$th of an inch was placed in a division $2\frac{1}{4}$ inches by 3 inches in one corner of the box, to avoid any agitation of the water surface in front of the scale. This division stopped short about 5 inches from the bottom of the box, so as to leave a free approach to the orifices. The water level was read by looking through the glass front along the surface of the water to the scale. The readings were probably not $\frac{1}{50}$th of an inch out. Each orifice was rated by measuring the discharge into another box, while a uniform head was maintained in the gauge box. The smallest head was 5 inches, and the largest 21 inches. Eighty-three of these observations were made, the duration varying from $4\frac{1}{2}$ minutes to 36 minutes, and the rise in the measuring vessel varying from 4 inches to 8·9 inches. The majority lasted over seven minutes, and had a rise of over 5 inches, the time being noted to a second, and the rise to $\frac{1}{100}$th of an inch.

The results for each orifice were very regular, with the exception of one, which gave very erratic results at first (probably on account of some obstruction), but finally gave a set just as good as the rest. The logarithms of the readings were plotted to a large scale, and give-and-take lines drawn through them from which the discharges were read off in reducing the results of the experiments with the $\frac{1}{2}$-inch pipe. The experiments with the pipe agreed very well with those of other observers, as shown by Diagram No. I., line 2A, which up to the critical point is practically on a 1 to 1 slope; at that point it curves over to about 3 to 1, and then up again to 1·80 to 1. The diameter of the pipe, as determined by weighing the amount of water required to fill it, was 0·49 of an inch. The velocities observed are given in Table I., where they are compared with the formula derived from Darcy's experiments.

Let D = the diameter of the pipe.
„ Q = the observed discharge.
„ L = the length of the pipe.
„ H = the head.

Let L be divided by H and the quotient called S. Then S is the cosecant of the angle of slope. There are then three

variables to be dealt with, namely, D, Q, and S. Let the results of experiments be reduced to these terms and plotted to scale, making the values of log S the abscissæ, and the values of log Q the ordinates. Then a line drawn through the points so obtained from experiments on a particular pipe will represent the law of discharge for that pipe, and the equation to the line will be the logarithmic homologue of the formula for the discharge. Of course there must be a different equation for the region below the critical point. Above this point the lines appear at first sight to be straight, but a careful examination shows that in most cases they bend slightly, not enough perhaps to be worth noticing in a formula to be applied to a limited range of velocity, except in the case of new cast iron when the bend is very marked and somewhat abrupt. This is a point which seems to have escaped the notice of Prof. Reynolds.

In looking for the slopes of the lines given by Darcy's experiments with cast-iron pipes, he seems to have run a give-and-take line through all the points obtained by experiments on each pipe, neglecting a bend which shows itself in some cases most clearly. Turning to Diagram I., line No. 19, which is the logarithmic homologue of the discharge curve for a new cast-iron pipe, ·137 m. (0·4495 foot) diameter, it will be observed that the majority of the points lie almost exactly on a slope of 2 to 1, while the three lowest points bend down to a steeper slope of about 1·78 to 1, and a line drawn through the whole would have a slope of about 1·88 to 1, which is what Professor Reynolds gives. Line No. 16 for a pipe of the same description ·0819 m. (0·2687 foot) in diameter, shows the bend still more clearly. In this case 8 out of 12 points are on a slope of 2 to 1, while the remaining four are on the steeper slope of 1·78 to 1, while a line through the whole has a slope of 1·86 to 1.

The dotted lines in the diagram are drawn at 2 to 1, in order to show the deviation clearly. The deviation is clearly shown in No. 14, which represents an old cast-iron pipe ·0795 m. (0·2608 foot) in diameter, and also in Nos. 15, 22, 24, and 28. On the other hand, Nos. 20, 25, 33, and 35 are on slopes of 2 to 1 with no deviation.

Taking the case of cast-iron pipes, the following points seem clear.

1st.—At high velocities the slopes are precisely 2 to 1.

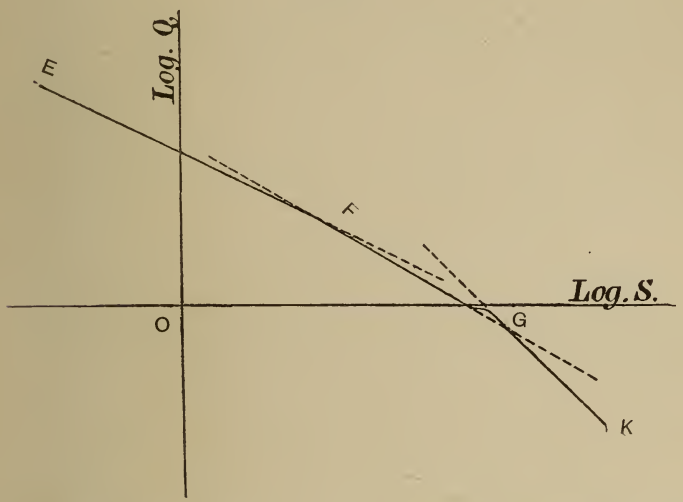
2nd.—With medium velocities slopes are rather steeper, being about 1·78 to 1 for cast iron.

3rd.—At very low velocities, and with very small pipes, the slopes will be 1 to 1.

This last point can hardly be disputed, although the author has no experiments with cast-iron pipes to refer to to prove it.

Hence the complete homologue for any pipe would appear to be similar to the line E F G K in Fig. 1, in which G K at 1 to 1 slope represents the law of stream line flow. The lump at G indicates the critical point, and the point F is the intersection point of the 2 to 1 slope with the steeper slope above the critical velocity. The lines probably always have a curve on them

Fig. 1.



at this region, but with cast iron it seems short, while with wrought iron it appears to be so long that the 2 to 1 slopes have not been reached in any experiments the author has come across, and while admitting the existence of the curve, he has thought it better to assume a slope which gives sufficiently accurate results within the range of velocities met with in practice. With Darcy's ·285 m. (0·935 foot) pipe, however (No. 27), the slope varies distinctly from 1·7 to 1·9 to 1, with velocities from 1·3 to 10·5 feet per second, and a slope taken at about 1·8 to 1 would involve an error of more than 5 per cent. in this case, which is one with an exceptionally sharp curve for a wrought-iron pipe. Table I. gives the figures, the column headed "Error per cent." showing the effect of the curve.

Again, Darcy's ·196 m. (0·643 foot) pipe shows the same curve, but to a very much smaller extent than the last, even with nearly double the range of velocities. It is difficult to account for such differences. With the author's ½-inch pipe the curve is fairly marked, the slope starting from the critical region with 1·75 to 1, and bending down to 1·90 to 1, with velocities over 2½ feet per second. In the Tables of Coefficients, at the end of the paper,

one value only is given for each material, except cast iron, for which two are given, one to represent the region E F, Fig. 1, and the other the region F G, and the correct one to accept is that which gives the smallest discharge.

Any line on the 2 to 1 slope is represented by an equation of the form

$$\log Q = O\,m - \tfrac{1}{2} \log S, \qquad (1)$$

in which $O\,m$ is a constant for each pipe and equals say $\log m$.

This logarithmic equation is the homologue of the equation

$$Q = \frac{m}{\sqrt{S}}, \qquad (2)$$

in which m is the number of which $O\,m$ is the logarithm.

Similarly, if the line is on a 1·80 to 1 slope, the equation will be

$$Q = \frac{m}{\sqrt[1\cdot 80]{S}}. \qquad (3)$$

Thus far the only difficulty is to determine the slope of the line joining the experimental points, which is the constant "n" in the formula (No. 6). The next step is to determine the variation of m with the diameter, and with the nature of the pipe. To arrive at these the homologues of equal velocity lines are added to the diagram as shown, a separate line for a particular velocity being drawn for each set of pipes answering to the same verbal description. From these lines a fairly accurate conclusion can be arrived at as to which of the pipes really were of the same roughness, and having decided on two or more as being good representatives, their experimental lines are produced (on the slope n to 1) to cut the axis of log Q, which gives the value of log m for each pipe. These values plotted as ordinates on Diagram II. (Plate 2), with the logarithms of the corresponding diameters as the abscissæ,* give a new line, the equation to which is the logarithmic homologue of the expression for the value of m in equation (2). The four lines shown on the diagram represent new cast iron, old cast iron, wrought iron, and lead, and at first sight they seemed to be straight lines parallel to one another, and on a slope of 2·6116 to 1, the equation to any line being therefore of the form

$$\log m = 2\cdot 6116 \log D - \log C, \qquad (4)$$

which is the logarithmic homologue of the equation

$$m = \frac{D^{2\cdot 6116}}{C} \qquad (5)$$

* The diameters are taken in inches in the diagram.

Substituting this value for m in equation (2), the following relation is established as the formula for discharge.

$$Q = \frac{D^{2 \cdot 6116}}{C \sqrt[n]{S}}. \qquad (6)$$

This is the formula arrived at by the author and already published.

If Q = discharge in cubic feet per second
S = the cosecant of the angle of slope
D = diameter of pipe in inches
C and n = coefficients depending on the nature of the surface of the pipe.

For very smooth new cast iron C = 13·665 and n = 2.
„ old encrusted „ C = 22·49 and n = 2.

Other values of C and n were given for different materials.

Putting A = sectional area of the pipe, and V = the mean velocity of discharge in feet per second.

Then Q = A V.

Substituting this for Q, equation (6) becomes

$$A V = \frac{D^{2 \cdot 6116}}{C \sqrt[n]{S}} \qquad (7)$$

$$V = \frac{4 D^{2 \cdot 6116}}{C \pi D^2 \sqrt[n]{S}}. \qquad (8)$$

Also, putting 48 R for D, R being the hydraulic radius in feet, and absorbing the constants derived from the change of units in the value of C, we get

$$V = \frac{R^{\cdot 6116}}{C \sqrt[n]{S}}. \qquad (9)$$

If the four lines on Diagram II. were parallel straight lines, the index of R would be a constant for all materials, and, judging from experiments with pipes only, it would be difficult to trace any systematic deviation, but with the results of experiments on open channels as a guide, it is easy to see that they are neither straight nor parallel, but curved and converging. Putting x instead of ·6116 as the index of R, we may pass on for the present to consider the results of

Experiments with open Channels.

It is more difficult to deduce the value of n from experiments with open channels than with pipes, because it is impossible to get a series of observations with a constant hydraulic radius and varying slopes in one particular channel, unless it be a small

experimental trough that can be tilted at different angles, and experiments with such troughs, although they might be useful in determining the value of "C" in the formula, could hardly be carried out on a sufficiently large scale to obtain the value of "n" in the equation with accuracy. Again, if we experiment with different channels of the same hydraulic radius but on different slopes, we are met with the uncertainty as to whether they actually were of the same roughness, although they might appear to be so.

Consequently we must content ourselves generally with a comparison of isolated observations on different channels, or with a series of observations on one channel running at different depths but keeping the slope constant.

Experiments of this latter class are by far the most useful, and we have the splendid series of Darcy and Bazin to start with, and also that of Major Cunningham on the Ganges Canal, besides many other more limited series by various observers. Plotting the logarithms of the observed velocities as abscissæ, and of the hydraulic radii as ordinates (Diagram III.), lines are obtained, the slopes of which give at once the indices of "R." These generally show a slight curve, especially with small values of R, and with rough channels; but above a certain value of R they are practically, though probably not actually, straight, and this value of R increases with the roughness, and is called z in the formula.* As every one knows, the most important result of Darcy's experiments was the proof that the nature of the surface very greatly affects the flow, but they also proved that the extent to which the flow is affected by the nature of the surface decreases as the hydraulic radius increases.

This second point is shown very clearly by the following table, which gives the powers of the hydraulic radius to which the velocity is proportional (the slope being constant), as shown by experiments with rectangular channels about 6 feet wide:—

Pure cement	v is proportional to $R^{\cdot 625}$
Brick, not very smooth	$R^{\cdot 65}$
Unplaned plank	$R^{\cdot 68}$ to $R^{\cdot 71}$
Small gravel ·03′ to ·07′ diam. fixed in cement ..	$R^{\cdot 733}$
Large gravel ·10′ to ·13′ diam. fixed in cement ..	$R^{\cdot 824}$

It is difficult to understand how this point has managed for over twenty years to escape the notice of the majority who have studied these experiments. Even Prof. Unwin has lately

* In some of the Darcy-Bazin experiments with open channels the results seem erratic in some cases where the depth of water was less than 6 inches, which may be accounted for by the fact that the bottom profiles were not all perfectly straight.

quoted as "satisfactory" a formula given by Prof. Osborne Reynolds, which not only neglects to show this decrease in the effect of roughness with an increase in hydraulic radius, but in some positively indicates the reverse state of affairs.

Prof. Reynolds' formula is—

$$\frac{h}{l} = m \frac{v^n}{d^{3-n}}, \tag{10}$$

or, putting $\frac{1}{S}$ for $\frac{h}{l}$ and taking $n = 2$,

$$v^2 = \frac{d}{m\,S}, \tag{11}$$

or,

$$v = \frac{d^{\cdot 5}}{\sqrt{m}\,\sqrt{S}}. \tag{12}$$

The author has not yet come across a single case where v varies as $d^{\cdot 5}$. With n equal to 2 the index of d is probably never less than ·61.

Taking $n = 1{\cdot}75$, equation (10) becomes

$$v^{1{\cdot}75} = \frac{d^{1{\cdot}25}}{m\,S} \tag{13}$$

or

$$v = \frac{d^{\cdot 71}}{\sqrt[1{\cdot}75]{m} \times \sqrt[1{\cdot}75]{S}}. \tag{14}$$

This is similar to Hagen's formula, and may be correct for very small smooth pipes, through a very small range of diameters; but Hagen's formula is stated as

$$v = \frac{d^{\cdot 66}}{c\,\sqrt[1{\cdot}75]{S}}, \tag{15}$$

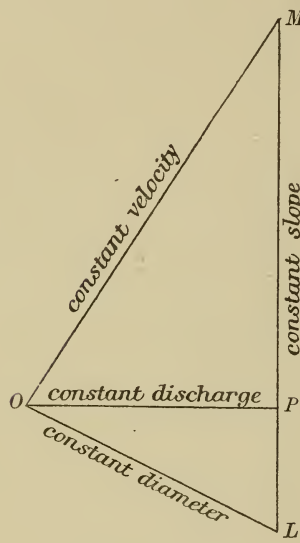
which is applicable over a much larger range, and has nothing to do with the mysterious d^{3-n}, which Prof. Reynolds has imported.

Kutter's formula will be referred to later on.

The open-channel experiments are located on the Diagram No. I. by calculating what the discharges would have been if the experiments had been with pipes of the observed hydraulic radius and with the observed velocities, and the logarithms of the discharges so found are plotted together with the logarithms of the observed slopes. This is necessary, because the sectional areas in open channels bear no fixed proportion to the hydraulic radii. It only involves the usual assumption that the theory

of the hydraulic radius is equally true for pipes and irregular channels. It is better to do this than to plot the logarithms of v and R, because the experimental points become more scattered on the diagram, and render it easier to detect any symmetry. Velocity lines can be added very easily, and when $n = 2$, they come out on slopes of x to 1.

FIG. 2.



$$L\,M = 2 + x$$
$$L\,P = x$$
$$P\,M = 2$$
$$\frac{O\,P}{L\,P} = n$$

If $n = 2$
$O\,P = 2\,L\,P$
$= 2\,x$

Referring to Fig. 2, L and M are two experimental points, whose distance apart we may call $2 + x$, for

A is proportional to R^2
and V „ „ R^x
also $Q = A\,V$ ∴ Q „ „ R^{2+x}

Let L P = x and P M = 2;

$\frac{O\,P}{L\,P} = n$, so if $n = 2$, then O P = 2 L P
= 2 x;

consequently O M is on a slope of x to 1.

This is only true when $n = 2$; but it is a very convenient coincidence.

The process of sifting the evidence as to the slopes of the velocity lines is a very laborious one, and need hardly be described in detail. It will be sufficient to state that, after a

careful examination of a large number of lines representing a velocity of 4 feet per second, the author concluded that for the larger values of R they varied from ·58 to about ·80 to 1, and that they would meet at a point on the diagram, the co-ordinates of which would be 6·9015 on the axis of log Q and 6·16758 on the axis of log S, which corresponds to a pipe 5646·8 feet in diameter (or over a mile), which with a velocity of 4 feet per second would discharge nearly 8,000,000 cubic feet per second. Assuming that the velocity lines do meet at this point, the inference is that with such a pipe the discharge would be the same whatever the nature of the surface. Of course it cannot be absolutely true, but the the error involved in assuming it to be so appears to be so very insignificant within the range of practice, that the author has adopted it to simplify the formula. The hydraulic radius of the pipe would be 1411·7 feet, or nearly twenty times that of the Mississippi at Carrollton, so that with rivers of the size of the Mississippi, the formula indicates that the nature of the surface has a very considerable influence on the flow, although very much less than with small channels.

On Diagram 1 a number of lines are shown, representing a velocity of 4 feet per second for different materials, and, if they are correct, all experimental points with $v = 4$ will be within the area covered by them. A few experiments with large rivers have given points outside this area, but they have all been cases in which the sectional area has not been the same at both ends of the reach where the slope was measured, consequently there must have been a change of velocity in the reach, which causes the measured slope to be very different from what may be termed the "frictional slope" S of the formula.

In all cases where there is a change of velocity between the points where the surface level is taken, the head due to the difference of velocities should be added to, or subtracted from the observed fall, as the case may be, and the slope calculated with the modified fall; it will then represent more closely the "frictional slope" of the formula. If this point were attended to by all observers, we should have a larger stock of reliable experimental data.

In the case of wrought-iron pipes, as shown in Table I., $n = 1·80$ and $x = ·65$, but the line representing $v = 4$, for these pipes meets the velocity line ·59 to 1 on Diagram I. Now, turning to Fig. 2, it will be seen that if L P = ·65 and $n = 1·8$, the slope of O M will be L P × n to 2, or 1·17 to 2, that is, ·585 to 1, to correspond with the ·59 to 1 just mentioned.

This agreement suggests the possibility of arriving at an approximately true value of n for materials with which we have only got experiments on one channel, and consequently at

one slope, the value of x being obtained by observing the velocity with various depths of water. In the table of coefficients (No. XVII.), some of the values of n have been obtained in this way from sets of experiments on one channel only. Any error involved is probably in the direction of making n a little too large.

For small values of R the index distinctly increases, and the point where the increase begins to be worth noticing is, as mentioned above, when $R = z$. The curve might be expressed in several ways, but a convenient and simple form is as given in the following equation which is the author's general formula for velocity.

$$v = \frac{R^{x+y\sqrt{\frac{z-R}{R}}}}{C\sqrt[n]{S}}. \qquad (16)$$

When R is greater than z, the second term of the index is neglected.

The effect of a change of temperature is not taken into account, as in a great many of the experiments no careful record was made, and even if it had been, it is doubtful whether a general expression could be framed with sufficient accuracy to make it worth introducing into the formula.

Table XVIII. gives the friction of water at various temperatures, taking the friction at 60° Fahr. as 100, the figures being derived from the experiments of Mair and Hagen on small pipes, and of Unwin on discs rotated in water.

In Tables I. to XVI. the temperature is given opposite some of the coefficients, so that any differences with a particular material may be traced to the temperature with the aid of Table XVIII. if possible.

Kutter's formula is simply the Chezy formula with an elaborate expression introduced to give a variable value to the coefficient, making it a function of R and S, as well as of the roughness of surface. It is inaccurate in several ways.

1stly.—The variation of the resistance with the velocity is assumed to be the same for brickwork, ashlar, new cast and wrought iron, and unglazed stoneware. Now considering the conspicuous difference between cast and wrought iron, it is impossible for the formula to be correct for both.

2ndly.—The variation of the velocity with the hydraulic radius is too large with small values of R (say less than 1), and too little with large values of R (say more than 4); or, in other words, the curve of the velocity lines (Diag. 1) is very much exaggerated by Kutter.

3rdly.—The velocity lines for different materials converge slightly but not nearly so much as they should do to indicate

truly the decrease in the effect of roughness with the increase of the hydraulic radius.

In the formula $v = c\sqrt{\mathrm{R}\,s}$. (17)

The value of c is given by Kutter as

$$c = 100 \left\{ \frac{\frac{1\cdot811}{\mathrm{N}} + 41\cdot6 + \frac{0\cdot00281}{s}}{1 + \left(41\cdot6 + \frac{0\cdot00281}{s}\right)\frac{\mathrm{N}}{\sqrt{\mathrm{R}}}} \right\} \qquad (18)$$

putting s = sine of slope = $\cdot00281$.

$$c = \frac{\frac{1\cdot811}{\mathrm{N}} + 42\cdot6}{1 + 42\cdot6\,\frac{\mathrm{N}}{\sqrt{\mathrm{R}}}}. \qquad (19)$$

$$\text{If } \mathrm{N} = \cdot010,\ c = \frac{223\cdot7}{1 + \frac{\cdot4260}{\sqrt{\mathrm{R}}}}$$

$$\mathrm{N} = \cdot020,\ c = \frac{143\cdot15}{1 + \frac{\cdot852}{\sqrt{\mathrm{R}}}}$$

$$\mathrm{N} = \cdot030,\ c = \frac{102\cdot96}{1 + \frac{1\cdot278}{\sqrt{\mathrm{R}}}}.$$

In the table below, the values of c are given for several values of R with the above three values of N, and the power of R to which c is proportional has been worked out, and this added to the index of R in the formula ($\cdot50$) gives the power of R to which the velocity is proportional. These powers are indicated by x in the table.

R.	64	16	4	1	$\frac{1}{4}$	$\frac{1}{16}$
N = $\cdot010$..c	212·4	202·1	184·4	156·9	120·8	77·03
x	·535	·566	·616	·688	·824	
N = $\cdot020$..c	129·4	118·02	100·39	77·3	49·3	
x	·566	·616	·688	·824		
N = $\cdot030$..c	88·84	78·03	62·81	45·2		
x	·593	·656	·737			

This shows that when $n = \cdot 010$ and R is between $\frac{1}{4}$ and $\frac{1}{16}$, x is about $\cdot 824$. Now, comparing this with the formula and results given in Table I., representing wrought iron, it is evident that $\cdot 824$ is much too high for even with the $\frac{1}{2}$-inch pipe. The index of R only reached $\cdot 6935$, whereas Kutter's formula would give it more than $1 \cdot 00$.

With R between $\frac{1}{4}$ and 1, x is still too high, while between 1 and 4 it is fairly accurate ; but there is no experimental evidence to show that it ever becomes less than $\cdot 616$.

Again, the results of experiments given in Tables XV. and XVI. go strongly to show that the values of x with $n = \cdot 020$ and $\cdot 030$ are far too small with large channels.

On the following points evidence is scarce.

With large cast-iron pipes at very low and also at high velocities.

With glazed stoneware-pipes under all conditions of flow which are met with in ordinary sewer work.

With pipes of all sorts running from half-full to full.

With brick and cement-rendered channels at very different slopes.

With open channels running at sufficiently different depths to give a variation of R from 1 to more than 3, or in a similar proportion.

With large rivers giving a variation of R in a ratio exceeding 2 to 1.

Mr. K. R. Bornemann describes some gaugings of the river Elbe, at Herrnskretchen, which led to the conclusion that the mean velocity was approximately proportional to $R^{\cdot 642}$. The experiments were made, however, in a length confined by stone revetments with slight curvature, which would tend to modify the coefficient of roughness as well as the index of R. The sectional areas varied from 119 to 245 square metres, and the hydraulic radii (not stated in the abstract now quoted) probably in a ratio of less than 2 to 1.

It may perhaps be thought that too much importance has been attached to the position of the critical point, but apart from the guidance it gives in working out a formula, it is worth consideration in practice. For instance, in apparatus used for cooling or warming liquids, it is a very common thing to pass the liquids somewhat slowly through small tubes surrounded by the substance to be cooled or warmed, as the case may be. Now, if the motion of the liquid be of the stream-line kind, the efficiency of the apparatus will depend very largely on the conducting power of the liquid in the tubes, but if the flow be of the eddying kind, a much larger proportion of the liquid will come in contact with the side of the tube, and it will exchange

heat much more rapidly. The essence of Lawrence's cooling apparatus is the creation of eddies in the liquid between corrugated plates. The efficiency of some surface condensers might possibly be improved by attention to this point.

The constants C, y, and z could not be connected together by one expression, because they are affected by the nature of the roughness, as well as by the actual irregularity of surface. It is capable of proof that two surfaces of a totally different nature may, with one particular value of R, and one particular value of S, give precisely the same velocity, while with other values of R on the same slope the velocity may differ to an almost incredible extent. The distinction between two such surfaces is mainly indicated by the values of y and z in the formula. No such distinction is recognised in any formula hitherto published.

DISCUSSION.

The PRESIDENT said it was his very pleasing duty to ask the meeting to accord—as he was sure that they would do heartily—their thanks to the author for the paper which had been read. It was a very satisfactory matter to him that, at the last meeting over which he should preside, a paper showing so much elaborate research had been brought before the Society by a gentleman with whom he had been associated for many years. After being a student at King's College, Mr. Thrupp was one of his (the President's) pupils, and he was now one of his most valued assistants. The older members of the profession would be glad to find one of the rising generation who was willing to devote whatever leisure he had from the hard work of life to original research, and the elaboration of the results of his observation. He thought that there was no subject more interesting to engineers than that which had been referred to by the author. A great deal of information existed, both in our own and in foreign languages, which had been available from the time of Torricelli in 1643 to the present day, but which had not been thoroughly digested until the last few years. Unwin, Mair, Reynolds, Cunningham, and others had supplemented the investigations of past observers, and the information which was now available had been utilised by Mr. Thrupp with very great skill, and had also been supplemented by some very valuable observations of his own. The paper was one which he should have liked to read carefully with the aid of the diagrams, and to discuss in a month or three months' time. Although the paper had been written and the diagrams prepared in his (the President's) office, he felt it right to say that the work was entirely Mr. Thrupp's.

Lieut.-Col. ALLAN CUNNINGHAM said that the paper was one which it was a great pleasure to hear, and one which he should have liked to study before discussing it. It was very difficult to speak about it usefully or critically off-hand, although it was illustrated by such valuable diagrams.

It was a pleasure to hear that Mr. Thrupp had himself been an experimenter. No one who had not himself experimented could have any idea of the great variations and unexpected changes which cropped up, or how difficult was the preparation of a formula. He believed that the symbols in the formulæ were not the same right through.

Mr. THRUPP said that they were not. Up to No. 16, S was the co-secant of the slope. In 17 and 18, s was the sine of the slope.

Col. CUNNINGHAM said that he believed that the quantity N, also, in Kutter's formula was distinct from Mr. Thrupp's n. In tracing the formulæ historically, from Chézy's downwards, one could see that there had been a process of elaboration from simple formulæ to more complex ones. He wished to ask whether the formula No. 9 was not nearly the same as Hagen's for pipes.

Mr. THRUPP replied in the affirmative.

Col. CUNNINGHAM said that it was, at all events, of the same functional form. He wished to call attention to this, viz. that the results for pipes were very much more regular than for open channels. The number of unknown and variable quantities was far fewer, and it was very much easier to make the formulæ harmonise satisfactorily with experimental data. Formula No. 9 seemed to follow Hagen's formula very closely. The next extension of it to open channels was a very much more complicated one. It involved, besides R, S, and n, three different quantities — x, y, and z — to be determined; and it was pretty complex. He had no doubt that the number of distinct physical quantities all connected together was really numerous, and that, to express them pretty fairly, a number of symbols was necessary in any formula. This was unfortunate for their calculations.

As to formula No. 16, he could only say that he was astonished at the industry that Mr. Thrupp must have given to the matter, to be able to deduce so complex a formula, and to make it harmonise so extraordinarily as it seemed to do throughout the diagrams. He observed a new departure in applying, not the results of the formulæ themselves, but the logarithmic values of the fundamental quantities Q, S, R, and D. This had led to a very great simplification in tracing out their relations. Instead of complex curves, they appeared to give only approximately straight lines. This was a very fortunate change, which had been introduced, he supposed, by the logarithmic plotting. In

Fig. 1 the lower part G K appeared to be the less practically useful one. He supposed that it obtained in pipes only, and in them, practically, only to a limited extent. Probably in all open channels the slope of the curve G E was the part to be taken, and the part below G did not come in at all. He supposed that the degree of agreement of the formula with experiment was to be traced to some extent, though not entirely, by the comparative straightness of the lines. It was wonderful to see that the lines were so straight. There was an immense difficulty in making a formula agree with the ever-varying conditions of data, and he was very pleased to see that the agreement was substantially so close. As to the quantities x, y, and z, he should like to know what they were. He assumed that z was of the nature of length, because R was subtracted from it.

Mr. THRUPP said that z was the value of R, at which the increase in the index began to make itself felt, and should be taken into account. It was the point on the diagrams where the curve began to be noticeable.

Col. CUNNINGHAM said that he supposed, then, that x and y were abstract quantities.

Mr. THRUPP said that it was so. x was the index of R above that point.

Mr. LOWIS D'A. JACKSON expressed his pleasure in having heard this paper on the subject of flow in pipes and channels. He wished to ask as to the velocities, whether they were taken simultaneously in section or not. Further, he wished to ask whether the formula was expressly made to suit pipes in the first instance, or originally as a general formula to include open channels as well. What was the first intention of the formula? It seemed to him that it might be suited to pipes very easily, as the form was applicable and the number of variables was large. He agreed with much that Col. Cunningham had said with regard to formulæ for pipes. He might mention that the errors in the coefficients of roughness and of velocity applied to Kutter's formula with regard to the cast iron, the wrought iron, the glazed stoneware, the new ashlar, and so forth, if they were errors, were all his own. Kutter did not mention any of those things in his books, as far as he remembered, though they were in his (Mr. Jackson's) own. Almost all the coefficients—the new ones that were not found in Kutter's book—were a revised new set, altered all through, and were all his own. He had made certain detached experiments of his own on the flow in pipes and sewers and some of the rivers and channels in India, which he had never published, for they were not a brilliant success when regarded as a complete series of experimental observations. Their irregularity,

however, did not prevent their being very useful to the observer. They enabled him, first, to form a series of tabulated coefficients of velocity for the old Chézy formula for different conditions and materials; and, secondly, they answered his purpose well in enabling him to form the new series of coefficients of roughness applied to Kutter's formula, whereby almost all the tabular velocities were altered. He thought that, on the whole, the formula of Mr. Thrupp and the explanation given of it were excellently applied, especially as regards pipes; but he thought that the formula was not suited to open channels of any sort, and had evidently not yet been thoroughly applied to them; though it was quite possible that so variable a formula might be adjusted to velocity observations, or *vice versâ*, in the cases of small channels. The old formula of Hagen, on which Mr. Thrupp's formula was based, was intended for large rivers only, but under Mr. Thrupp's process became applicable to pipes. This method was a very old one. For instance, the Dupuit formula for rivers was converted into a pipe formula, and the tables of Claudel thus formed were used in Italy, in Lombardy and Piedmont, he believed, to the present day, though they were not much known in England. The old Dubuat formula for river flow, also, was clipped into numerous shapes—perhaps a dozen pipe formulæ were made out of it in England, and were in common use until 1875 generally, and partially even till now. This practice of converting river formulæ into pipe formulæ has thus been carried out in many instances; and it may yet be effectively continued in many others, for at the two extreme conditions of full pipes and very flat, wide river channels there is one strong similarity, an even regular distribution of velocity in the section. Whether the results of refashioning old formulæ in this manner were at all commensurate with the labour, might be doubted; but he thought that much praise was due to Mr. Thrupp for the labour taken in observations on pipes, and in comparing and tabulating the velocity observations of various observers.

Mr. King said that Colonel Cunningham had so fully gone into the subject, that all that he (Mr. King) would have to say would be but a repetition. Mr. Thrupp deserved great praise for doing so much hard work, but the result looked very staggering after the simpler formulæ which they had had before.

Mr. Arthur Rigg said that he had listened with very great interest to the paper. Having designed and manufactured turbines for a great many years, he had often found the need of reliable data as to the flow of water in pipes. If the results given this evening were calculated out in tables,

engineers would find them more useful than in their present form, as few men had time to make the various calculations. Three years ago he made a number of experiments on the flow of water through pipes, entirely with the object of ascertaining the best mode of construction for the buckets of turbines. He found from those experiments one curious result, which was that the guides for the turbines should be smooth, although whether the buckets were smooth or rough did not make any appreciable difference in the working of the turbine. A practical result of this kind was of great use, because the trouble that we had previously taken in polishing up the turbine buckets made them cost more than foreign turbines made with rough buckets, and this discovery enabled a reduction in cost to be made without impairing the efficiency.

With regard to the apparatus used by Mr. Thrupp, it almost seemed that an excess of pressure must take place at the right-hand connection, while at that on the left a suction would take place, which might disarrange the pressures for which the flow was ascertained. There was a still more important point in the connections marked C and D. The indiarubber pipes led from holes in the pipe under experiment to the water-gauges in the centre. Now, when a flow of water passed a hole bored at right angles to the pipe, they never got the real pressure which was due to the head. They might have water of any pressure they liked going through the pipe, and if it was passing at a high velocity, not a drop would come out of such a hole. Therefore he thought that the pressure-gauges in the centre did not give any accurate measure as to the actual heads of water at the two points. It appeared as if the pressure at C would be observed as lower, and that of D as higher than they were in fact. Possibly there was some provision in forming the holes and connections which had not been fully explained. Some years ago a paper was read at the Society on Berthon's Log, which was used to ascertain the speed of vessels. It consisted of a vertical pipe closed at one end, and having a hole in the side of pipe, which was intended to raise a column of water indicating the exact pressure. If turned too much one way, the log indicated too high a result, and if turned too much back, it gave too low a result; but at a certain point between the two a correct indication was given. Possibly some such method might have been adopted by Mr Thrupp; if not, he (Mr. Rigg) should not feel full confidence in the results given by the apparatus. The formulæ require more careful study than can be given in a discussion taken immediately after such an elaborate paper has been read, but their interest is very great.

Mr. T. Hennell said that to enable them to discuss the subject properly would require three months' study. He had made experiments from time to time on the flow in open channels, or rather in sewers, and he should be very glad if he could make them of any use. He had observed the velocities in some long lengths of sewers, and had also calculated them according to the formula generally used, which appeared to him to be the same as that numbered 17 on the table. He knew it in a slightly different form, but he thought that it must be practically the same. He might say, in a few words, that the conclusion to which he came was, that for small sewers the formula in use always gave too high a velocity, and that in large sewers the velocity given was too low. As the result of a great many trials in different places on long lengths, he found that, with a sewer of 2 feet 3 inches diameter, the actual velocity was almost identical with the theoretical velocity. With very small pipes he found the formula useless. Of course there was a difference between the flow of sewage and the flow of water; and he thought that in the case of small pipes the experiments on sewers ought to be eliminated, because the difference between the flow of sewage and the flow of water in small pipes was considerable, though in large pipes it was probably inconsiderable. Experimenting with a 2-feet sewer, he went through one long length for several miles, and found that with an inclination of 1 in 500 in a length of 4370 feet, without any change of gradient, and with a uniform depth of $5\frac{3}{4}$ inches, the velocity of flow tried at intervals was 125 feet per minute. The theoretical velocity was 133. The subjoined table, communicated for insertion in the 'Transactions,' gives the result of Mr. Hennell's observations.

Some Experiments on the Velocity of Flow in Circular Sewers.

Diameter of Sewer.	Description.	Depth of Sewage flowing.	Gradient.	Length experimented upon.	Velocity of Float in Centre of Stream.	Average Velocity calculated at $\frac{4}{5}$ths of that in Centre.	Velocity calculated by Eytelwein's Formula.
in.		in.		ft.	ft. per min.	ft. per min.	ft. per min.
15	Stoneware pipe	6	1 in 330	1605	200	160	205
24	,,	$5\frac{3}{4}$	1 in 500	4370	125	100	133
24	,,	6	1 in 600	740	123	98	124
24	,,	$6\frac{3}{4}$	1 in 500	1320	125	100	143
24	,,	$6\frac{1}{4}$	1 in 264	711	190	152	198
24	,,	8	1 in 400	690	166	132	171
27	,,	7	1 in 832	316	136	109	112
27	,,	9	1 in 832	316	140	122	124
66	Concrete sewer	$11\frac{3}{4}$	1 in 1260	680	180	144	122
66	,,	$13\frac{1}{4}$	1 in 1260	680	190	152	129

In answer to the President, Mr. Hennell stated that he generally used oranges as floats, sometimes blocks of some heavy wood, but in all cases something that was very nearly submerged.

Col. CUNNINGHAM, supplementing his former remarks, said that it would greatly contribute to the interest of Mr. Thrupp's paper if he would kindly tell them shortly what was the range of his data in tabulating the results which he had put forward; what was the lowest, and what was the highest velocity? what was the smallest, and what the highest discharge? and similarly for the hydraulic mean depth and slope; and so on for every one of the different data. With regard to a formula of any sort, the agreement (between formula and experiment) for pipes seemed to be pretty good, but in open channels it was difficult to ensure agreement. Now in all natural open channels the slope was small, and often minute. The difficulty of measuring a minute slope was very great, and the error likely to be made in measuring this small quantity S was proportionately large, and that error was probably itself accountable for the extreme difficulty of making formulæ agree with experiment.

Mr. THRUPP, in reply, said that he quite realised what Col. Cunningham said about unexpected variations in making his experiments, and the results which he had given for the velocities observed were in nearly every case the mean of about half-a-dozen readings. The formula No. 9, which he arrived at, was the same as Hagen's, but he obtained it without any idea of what he was coming to, by plotting diagrams Nos. I. and II., and working it out by the logarithmic equations (1) and (4). Very likely Hagen arrived at his in exactly the same way. As to the complication of the power of R with smooth channels, it was only with a very small hydraulic radius that the complicated part of the index came in at all. Above a certain point Hagen's formula was accurate enough. The velocity lines, which were practically straight above that point, began to curve below it, and varied with the varying roughness of surface. For instance, for wrought-iron pipes less than 9 inches diameter, the velocity line was curved at the point shown on diagram No. I. With large open channels the curve began much higher up, as shown by the experimental velocity lines. Probably it was not worth while putting z anywhere higher than 5 or 6.

With regard to the 1-to-1 slopes, it was only with extremely small pipes that they were likely to get them at all in practice. In quarter-inch pipes the critical point was only reached with a gradient of 1 in 10. In half-inch pipes at about 1 in 100. In No. 5 (a pipe about 1 inch diameter) at 1 in 1000; and with

No. 13, a 2½-inch lead pipe, the critical point was not reached until the gradient was 1 in 10,000, which of course was not likely to occur in practice at all. As to the range of the experiments; beginning at the bottom of the diagram, he had a quarter-inch pipe with gradients from 1 in 100 to a gradient which might be said to be more than vertical, because the loss of pressure was greater than that due to a column of water as high as the length of the pipe. The experiments with pipes extended up to pipes of 4 feet in diameter, which were experimented upon by Mr. Stearns in America. The two dots at the top of the diagram indicated the experiments of Humphreys & Abbot on the Mississippi at Carrollton. He did not quite understand what Mr. Jackson meant in asking whether the velocities were observed simultaneously.

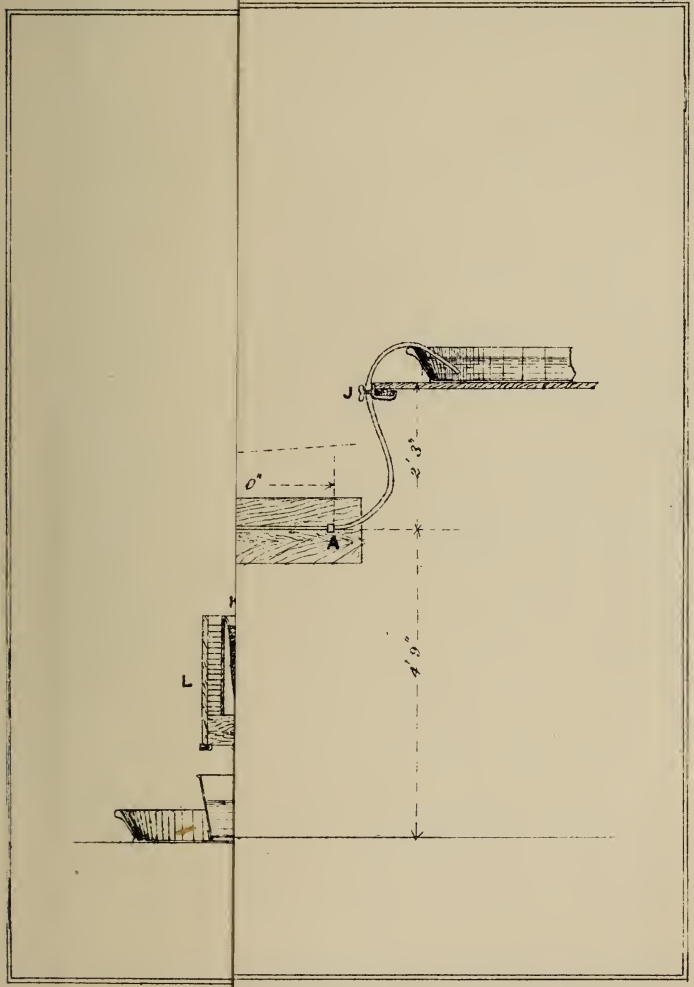
Mr. JACKSON said that he meant to ask whether in any section of open channel on which observations were taken the velocities in the section were observed at the same time.

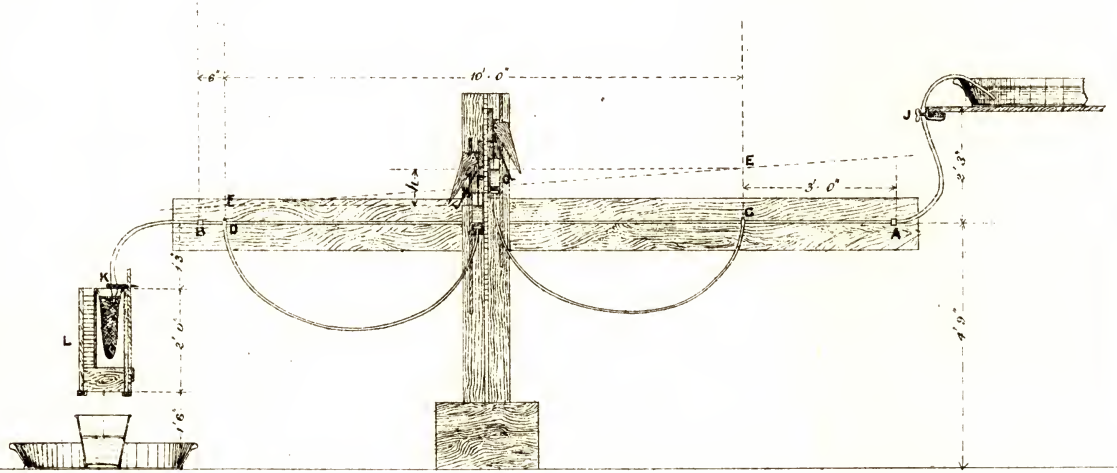
Mr. THRUPP said that he did not think that they were. Some of the experiments were made by Colonel Cunningham, and perhaps he could answer the question better.

Mr. Jackson had further asked whether the formula was made to agree with pipes, and stated that it would be more suitable for pipes than for open channels. He would reply that it was not made particularly to agree with pipes. He first arrived at the formula No. 6, and then he plotted the lines representing the results of experimeuts in open channels for comparison with it. He found a slight curve in some of them, and found that they came at different slopes. He then introduced the modification in the power of R, for small values of R. In Diagram III. the horizontal line marked $\overline{1}$ represented the hydraulic radius of $\frac{1}{10}$ of a foot, and the line marked O represented the hydraulic radius of 1 foot. Above that line, that is to say, with R, greater than 1 foot, it was not worth while to notice the second part of the expression, except in the case of very rough channels, and in that case the value of z might go up as high as 4 or 5.

In Table No. XV. he had not put in that expression at all. He believed that it ought to be put in, but the data which he had at hand were not sufficiently symmetrical for him to be able to determine with accuracy what the value of z was in that case. The fact of getting an error of 12·2 per cent. in the first experiment in that table showed that there ought to have been a curve introduced. It was probably on account of the omission of the curve in that table that Mr. Jackson did not think that the formula would be suitable for open channels. He did not quite agree with him. He thought that the values of y and z

Plate 1.





E. & F.N. Spon, London & New York.

LIBRARY
OF THE
UNIVERSITY OF ILLINOIS

DIAGRAM Nº I.

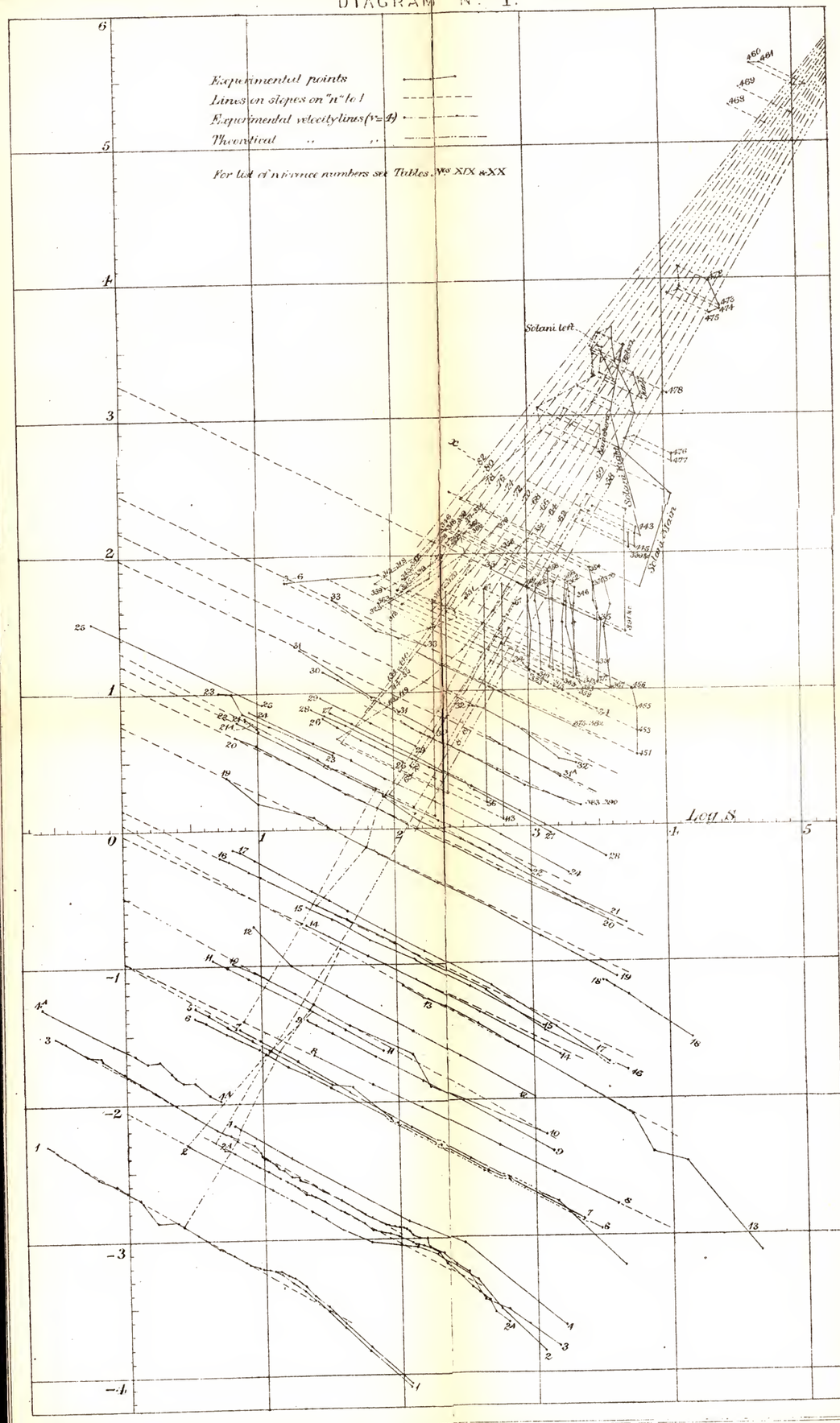


DIAGRAM Nº II.

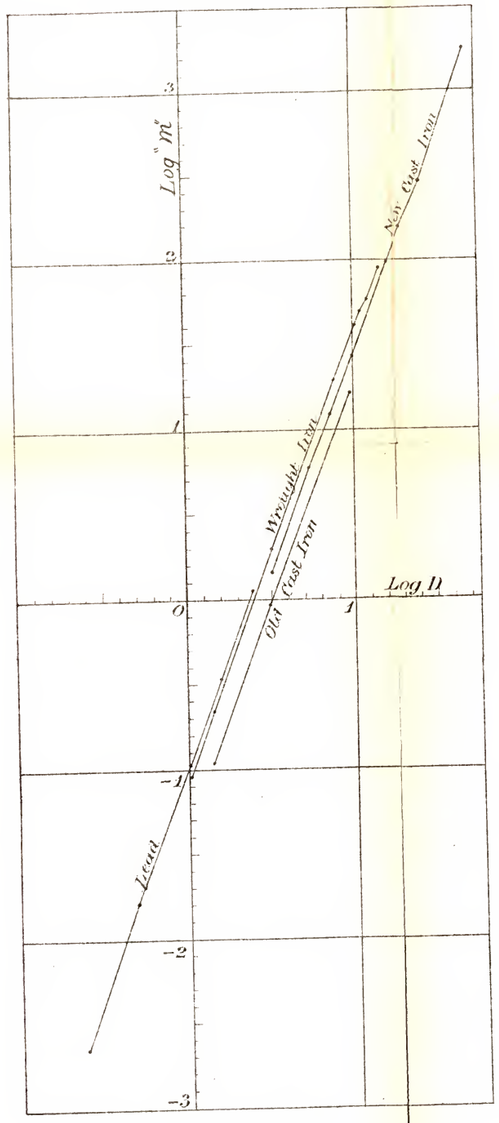
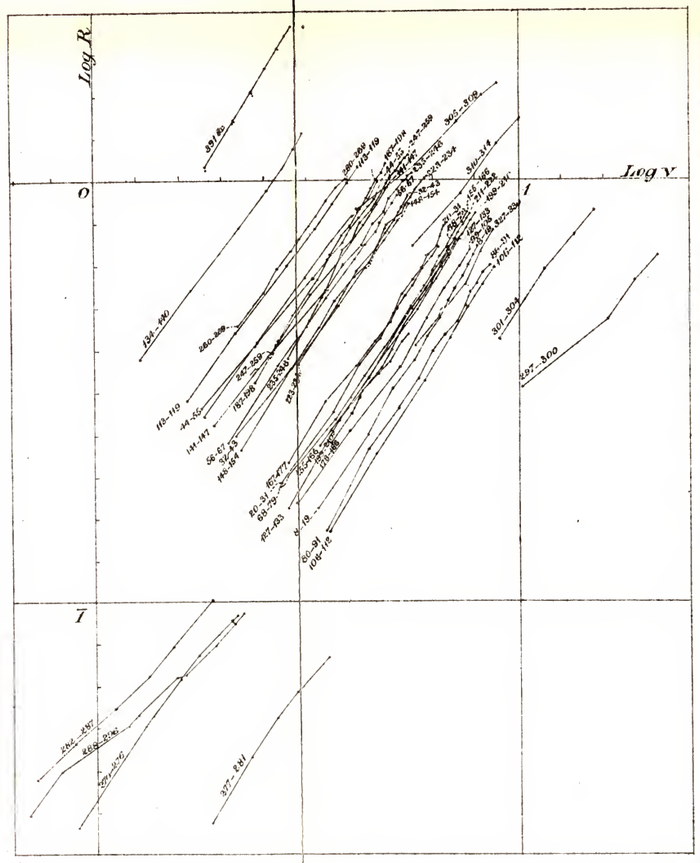


DIAGRAM Nº III.



E & F.N. Spon, London & New York.

might make it practically the same as Kutter's. Mr. King had complained that the formula was rather staggering. He (Mr. Thrupp) had already explained that for pipes above 9 inches in diameter it was not worth while to notice the second part of the index of R, so that it came down to a simple form in large pipes.

Mr. Rigg had made some remarks about the holes in the pipes. If two holes were made exactly alike in the half-inch pipe (see Plate I), the velocities passing both of them must be precisely the same; and he did not see why the head in one gauge-glass should differ from the actual pressure any more than in the other. He believed that in the whole of Darcy's experiments the head was measured in precisely the same way. He was much obliged to Mr. Hennell for giving the results of the experiments which he had made. He did not see why they should not know exactly what the velocity of sewage was, instead of confining themselves simply to pure water, which was not what they had to deal with in sewers.

APPENDIX.

NOTE.—The reference numbers in the following tables (I. to XVI.) are the same as those used in Mr. Hamilton Smith's work on "Hydraulics."

Hagen's formula, as proposed to be modified:—

$$v = \frac{R^{x + y\sqrt{\frac{z - R}{R}}}}{C\sqrt[n]{S}}$$

TABLE No. I.

Wrought-iron pipes. $n = 1{\cdot}80$, $C = 0{\cdot}004787$, $x = {\cdot}65$, $y = {\cdot}018$, $z = {\cdot}07$

Temp. 70° F.

Reference Number.	Diameter in feet.	S.	Velocity in ft. per sec.		Error per cent.	Name of Observer
			Observed.	By formula.		
166	0·935	1428	1·296	1·435	+10·7	Darcy.
167	„	389·3	2·782	2·943	+ 5·8	„
168	„	230·9	3·868	3·949	+ 2·1	„
169	„	145·9	4·902	5·096	+ 3·8	„
170	„	84·03	6·673	6·769	+ 1·4	
171	„	48·92	8·852	9·355	+ 5·7	„
172	„	35·62	10·522	11·156	+ 6·14	„
				Mean	+ 5·09	
155	0·643	4999	0·591	0·5616	− 4·97	„
156	„	2083	0·912	0·9135	+ 0·11	„
157	„	775·2	1·529	1·582	+ 3·46	„
158	„	303·0	2·559	2·665	+ 4·14	„
159	„	172·4	3·530	3·648	+ 3·37	„
160	„	84·03	5·436	5·436	0·00	„
161	„	83·33	5·509	5·461	− 0·87	„
162	„	47·61	7·411	7·452	+ 0·55	„
163	„	33·67	9·00	9·034	+ 0·36	„
164	„	27·47	10·013	10·116	+ 1·28	„
165	„	8·226	19·72	19·767	+ 0·24	„
				Mean	+ 0·69	

TABLE No. I.—*continued.*

Temp. 70–72° F.

Reference Number.	Diameter in feet.	S.	Velocity in ft. per sec.		Error per cent.	Name of Observer.
			Observed.	By formula.		
143	0·271	3704	0·328	0·374	+14·2	Darcy.
144	„	1515·2	0·577	0·6155	+ 6·70	„
145	„	492·6	1·171	1·149	− 1·88	„
146	„	159·0	2·182	2·149	− 1·56	„
147	„	81·96	3·117	3·111	− 0·19	„
148	„	43·76	4·442	4·410	− 0·72	„
149	„	32·18	5·292	5·230	+ 0·72	„
150	„	24·62	6·148	6·070	− 1·25	„
151	„	13·94	8·438	8·324	− 1·35	„
152	„	9·38	10·535	10·374	− 1·53	„
153	„	7·204	12·034	12·013	− 0·17	„
154	„	6·408	12·786	12·823	+ 0·29	„
				Mean	− 0·76	
				(Omitting Nos. 143 and 144.)		
Temp. 51-60° F.						
131	·0879	4544·7	0·098	0·1466	+50·0	„
132	„	1492·5	0·302	0·272	− 9·0	„
133	„	446·63	0·509	0·532	+ 4·5	„
134	„	164·20	0·889	0·9275	+ 4·5	„
135	„	88·247	1·260	1·187	− 5·8	„
136	„	45·025	1·860	1·903	+ 2·32	„
137	„	32·949	2·224	2·264	+ 1·78	„
138	„	22·029	2·798	2·831	+ 1·19	„
139	„	8·442	4·813	4·824	+ 0·22	„
140	„	5·560	6·099	6·083	− 0·26	„
141	„	4·895	7·228	7·210	− 0·25	„
142	„	3·256	8·225	8·189	− 0·43	„
				Mean	+ 0·77	
				(Omitting Nos. 131 and 132.)		

Reference Letter.	Temp. Fahr.	S.	Velocity in ft. per sec.		Error per cent.	Remarks.
			Observed.	By formula.		
a	52°·75	5·058	3·530	3·532	+ 0·05	Wrought-iron pipe ·49 in. diam.*
b	„	5·662	3·514	3·325	- 5·37	
c	52·50	6·095	3·294	2·185	- 3·4	
d	52·25	7·178	3·012	2·912	- 3·32	Name of observer, Thrupp.
e	„	8·091	2·850	2·721	- 4·52	
f	52·00	8·649	2·746	2·622	- 4·51	
g	61·00	9·225	2·665	2·529	- 5·10	
h	54·25	10·89	2·447	2·307	- 5·72	Mean error from "a" to "t" -3·888.
i	53·75	12·94	2·222	2·101	- 5·44	
j	61·00	14·72	2·083	1·959	- 5·95	

* N.B.—This pipe was not *drawn*.

TABLE No. I.—*continued.*

Reference Letter.	Temp. Fahr.	S.	Velocity in ft. per sec.		Error per cent.	Remarks.
			Observed.	By formula.		
k	53°·50	16·67	1·935	1·820	- 5·95	
l	,,	20·18	1·651	1·637	- 0·84	
m	,,	23·06	1·587	1·521	- 4·20	
n	53·25	27·41	1·465	1·381	- 5·73	
o	61·00	28·38	1·383	1·356	- 1·97	
p	53·25	35·81	1·227	1·192	- 2·87	
q	54·50	38·19	1·199	1·149	- 4·20	
r	54·50	52·36	1·006	0·964	- 4·20	
s	,,	60·11	0·887	0·894	+ 0·78	
t	,,	70·79	0·863	0·817	- 5·3	
u	,,	81·66	0·837	0·754	- 9·97	Near critical point.
v	,,	93·97	0·785	0·699	- 10·96	
w	,,	121·0	0·726	0·605	- 13·90	
x	,,	125·0	0·703	0·594	- 15·50	
y	,,	129·4	0·696	0·584	- 16·18	
z	,,	145·2	0·693	0·547	- 21·07	
a_1	,,	191·8	0·683	0·468	- 23·64	
b_1	,,	217·2	0·632	0·437	- 30·00	
c_1	,,	330·3	0·322	0·346	+ 7·60	
d_1	,,	396·2	0·280	0·320	+14·16	
e_1	,,	434·5	0·259	0·298	+14·76	
f_1	,,	476·4	0·213	0·283	+32·92	
g_1	,,	602·5	0·242	0·258	+33·94	

TABLE No. II.

Riveted sheet-iron pipes. $n = 1·825$, $C = 0·005674$, $x = 0·677$

Reference Number.	Diameter in feet.	S.	Velocity in ft. per sec.		Error per cent.	Name of Observer.
			Observed.	By formula.		
340	0·911	30·22	10·021	9·998	- 0·31	Hamilton Smith
341	,,	39·08	8·659	8·685	+0·30	,,
342	,,	59·00	6·927	6·932	+0·07	,,
343	,,	74·96	6 094	6·078	- 0·26	,,
344	,,	117·64	4·712	4·748	+0·77	,,
				Mean	+0·112	
345	1·056	30·14	10·706	11·064	+3·30	
346	,,	45·066	8·646	8·877	+3·30	,,
347	,,	70·03	6·962	6·973	+0·15	,,
348	,,	149·70	4·595	4·599	+0·07	,,
				Mean	+1·68	,,

TABLE No. II.—*continued.*

Reference Number.	Diameter in feet.	S.	Velocity in ft. per sec.		Error per cent.	Name of Observer.
			Observed.	By formula.		
349	1·23	30·95	12·090	12·246	+1·20	Hamilton Smith
350	„	40·49	10·593	10·438	-1·47	„
351	„	60·75	8·462	8·356	-1·27	„
352	„	81·50	7·314	7·114	-2·72	„
353	„	91·16	6·841	6·693	-2·26	„
354	„	199·21	4·383	4·359	-0·54	„
				Mean	-1·176	
356	1·416	14·98	20·143	19·796	-1·72	„
286	2·43	85·32	10·78	11·00	+2·0	„
				Mean error for five pipes	+0·18	

TABLE No. III.

	A.	B.
New cast-iron pipes.	$n = 1·85$	$n = 2·00$
	C = 0·005347	C = 0·006752
	$x = 0·67$	$x = 0·63$

Reference Number.	Diameter in feet.	S.	Velocity in ft. per sec.		Error per cent.	Remarks.
			Observed.	By formula.		
206	0·2687	5000·0	0·289	0·307	+ 6·2	Name of observer, Darcy.
207	„	1204·8	0·561	0·661	+18·1	
208	„	431·0	1·175	1·154	− 1·76	A.
209	„	188·3	1·841	1·808	− 1·80	
210	„	98·04	2·595	2·570	− 0·96	Temp. 57–65° F.
211	„	44·35	3·888	3·946	+ 1·48	
				Mean	− 0·76	
				(Omitting Nos. 206 and 207.)		
212	„	31·18	4·652	4·842	+ 4·09	B.
214	„	10·47	8·048	8·354	+ 3·80	
216	„	8·35	8·924	9·356	+ 5·10	
218	„	5·86	10·712	11·171	+ 4·30	
				Mean	+ 4·32	

TABLE No. III.—*continued.*

Reference Number.	Diameter in feet.	S.	Velocity in ft. per sec.		Error per cent.	Remarks.
			Observed.	By formula.		
219	0·4495	4167·0	0·489	0·477	− 2·44	Name of observer, Darcy.
220	„	1149·5	0·978	0·957	− 2·14	A.
221	„	478·4	1·601	1·537	− 4·00	Temp. 59–61° F.
222	„	210·5	2·503	2·395	− 4·30	
223	„	79·4	4·196	4·059	− 2·85	
				Mean	− 3·15	
223	„	79·4	4·196	4·196	0·00	B.
224	„	44·95	5·623	5·576	− 0·82	
225	„	30·14	6·883	6·809	− 1·05	
226	„	25·61	7·484	7·421	− 0·83	
227	„	10·15	11·942	11·733	− 1·76	
228	„	5·96	15·397	15 305	− 0 68	
				Mean	− 0·86	
229	0·6168	3703·4	0·673	0·629	− 6·48	A.
230	„	571·5	1·631	1·728	+ 5·98	
231	„	271·8	2·487	2·582	+ 3·83	
232	„	124·22	3·701	3·943	+ 6·54	Name of observer, Darcy.
233	„	74·63	4·882	5·190	+ 6·40	
				Mean	+ 3·25	
234	„	44·44	6·342	6·84	+ 7·87	B.
235	„	26·25	8·222	8·90	+ 8·30	
236	„	9·107	14·183	15·11	+ 6·54	
237	„	6·853	16·168	17·42	+ 7·77	
				Mean	+ 7·62	
276	1·373	613·5	2·709	2·843	+ 4·96	Name of observer, A. [Lampe.
277	„	726·8	2·479	2·594	+ 4·66	Temp. 47° F.
278	„	1684·6	1·577	1·647	+ 4·45	
				Mean	+ 4·69	
262	1·6404	2222·0	1·380	1·597	+15·77	Name of observer, A. [Darcy.
263	„	„	1·472	„	+ 8·52	
264	„	1667·0	1·559	1·867	+22·5 (?)	
265	„	833 3	2·602	2·715	+ 4·33	
				Mean	+ 11·78 (?)	
				(Omitting No. 262.)		

TABLE No. III.—*continued.*

Reference Number.	Diameter in feet.	S.	Velocity in ft. per sec.		Error per cent.	Remarks.
			Observed.	By formula.		
285	4	540·8	6·195	6·37	+ 2·83	B. Name of observer, Stearns.
283	„	1392·6	3·738	3·738	0·00	A. Temp. 38° F.
284	„	819·0	4·965	4·980	+ 0·30	
285	„	540·8	6·195	6·232	+ 0·60	
				Mean	+ 0·30	

TABLE No. IV.

Lead pipes of usual sizes. $n = 1·75$ $C = 0·005224$ $x = 0·62$

Reference Number.	Diameter in feet.	S.	Velocity in ft. per sec.		Error per cent.	Name of Observer.
			Observed.	By formula.		
1 *l*	0·02017	7·28	2·200	2·399	+ 9·0	Osborne Reynolds.
2 *l*	(·242″)	4·68	2·761	3·088	+11·8	„
3 *l*	„	2·33	4·319	4·600	+ 6·5	„
4 *l*	„	1·22	6·26	6·66	+ 6·3	„
5 *l*	„	0·615	9·20	9·84	+ 7·0	„
6 *l*	„	0·350	13·08	13·59	+ 6·3	„
7 *l*	„	0·258	15·87	16·17	+ 1·9	„
				Mean	+ 7·0	
8 *l*	0·0415	37·3	1·441	1·454	+ 0·93	„
9 *l*	(·498″)	18·3	2·142	2·184	+ 1·93	„
10 *l*	„	12·4	2·682	2·728	+ 1·72	„
11 *l*	„	9·35	3·266	3·207	− 1·82	„
12 *l*	„	4·67	4·862	4·768	− 1·94	„
13 *l*	„	0·962	12·56	11·76	− 6·40	„
14 *l*	„	0·368	20·98	20·36	− 2·97	„
				Mean	− 1·22	
112	0·0459	116·0	0·807	0·793	− 1·75	Darcy.
113	„	39·58	1·463	1·466	+ 0·20	„
114	„	16·27	2·402	2·437	+ 1·44	„
115	„	8·742	3·438	3·475	+ 1·60	„
116	„	6·193	4·232	4·232	0·00	„
				Mean	+ 0·29	

TABLE No. IV.—*continued.*

Reference Number.	Diameter in feet.	S.	Velocity in ft. per sec.		Error per cent.	Name of Observer.
			Observed.	By formula.		
118	0·0886	333·3	0·617	0·652	+ 5·73	Darcy.
120	„	44·09	1·959	2·073	+ 5·80	„
122	„	9·524	4·718	4·975	+ 5·47	„
				Mean	+ 5·66	
124	0·1345	1219·3	0·394	0·403	+ 2·21	„
127	„	43·29	2·598	2·713	+ 4·42	„
129	„	9·03	6·316	6·643	+ 5·20	„
				Mean	+ 3·94	
15 *l*	0·2083	5300	0·223	0·228	+ 2·4	James Leslie.*
16 *l*	($2\frac{1}{2}$″)	760	0·715	0·692	− 3·3	„
17 *l*	„	230	1·47	1·370	− 6·5	„
18 *l*	„	111	2·09	2·08	− 0·5	„
				Mean	− 2·0	

TABLE No. V.

Open channel, semicircular (4·1 ft. diam.). $n = 1·74$
Pure cement $C = 0·004$
$x = 0·67$

Temp. 63° F.

Reference Number.	Hydraulic radius in feet.	S.	Velocity in ft. per sec.		Error per cent.	Names of Observers.
			Observed.	By formula.		
223	·366	192·27	3·02	3·037	+0·56	Darcy and Bazin.
224	·503	„	3·72	3·757	+1·01	
225	·605	„	4·16	4·252	+2·24	
226	·682	„	4·60	4·607	+0·17	
227	·750	„	4·87	4·911	+0·71	
228	·809	„	5·12	5·166	+0·91	
229	·867	„	5·29	5·412	+2·32	
230	·915	„	5·51	5·611	+1·84	
231	·949	„	5·75	5·75	0·00	
232	·992	„	5·91	5·92	+0·25	
233	1·029	„	6·06	6·07	+0·18	
234	1·034	„	6·11	6·09	−0·32	
				Mean	+0·82	

* Min. Proc. Inst. C.E., vol. xiv. p. 273.

Table No. VI.

Open channel, rectangular (5·94 ft. wide) $n = 1·95$
Pure cement $C = 0·006429$
$x = 0·61$

Temp. 54° F.

Reference Number.	Hydraulic radius in feet.	S.	Velocity in feet per second.		Error per cent.	Names of Observers.
			Observed.	By formula.		
8	·168	204·1	3·34	3·348	+0·24	Darcy & Bazin.
9	·251	„	4·39	4·376	−0·29	
10	·322	„	5·04	5·095	+1·08	
11	·375	„	5·68	5·591	−1·55	
12	·430	„	6·08	6·078	−0·04	
13	·474	„	6·51	6·450	−0·91	
14	·518	„	6·83	6·809	−0·30	
15	·558	„	7·12	7·125	+0·09	
16	·595	„	7·41	7·410	0·00	
17	·632	„	7·63	7·688	+0·76	
18	·665	„	7·86	7·930	+0·78	
19	·696	„	8·07	8·154	+1·04	
				Mean	+0·075	
443	2·111	6330	2·805	2·757	−1·71	Fteley and Stearns.
444	2·048	6267	2·672	2·721	+1·83	
445	1·863	6227	2·529	2·577	+2·10	
				Mean	+0·74	

Table No. VII.

Brickwork (in good condition) $n = 2·00$
$C = 0·007746$
Open channel 9 feet wide, with curved bottom and sides $x = 0·61$

Reference Number.	Hydraulic Radius in Feet.	S.	Velocity in ft. per sec.		Error per cent.	Names of Observers.
			Observed.	By Formula.		
400	1·0709	5282	1·844	1·844	0·00	Fteley and Stearns.
392	1·3723	5248	2·131	2·161	+1·44	„
402	1·3779	5270	2·155	2·164	+0·42	„
403	1·6193	„	2·366	2·386	+0·83	„
396	1·8428	5295	2·564	2·576	+0·47	„
405	1·8395	5254	2·572	2·583	+0·42	„
406	2·0441	5264	2·731	2·750	+0·72	„
398	2·1916	5276	2·831	2·868	+1·32	„
407	2·1902	5304	2·834	2·859	+0·88	„
408	2·3297	5294	2·937	2·972	+1·40	„
				Mean	+0·79	

TABLE No. VII.—*continued.*

Open channel similar to last.

Reference Number.	Hydraulic Radius in Feet.	S.	Velocity in ft. per sec.		Error per cent.	Names of Observers.
			Observed.	By Formula.		
451	0·4925	6098	1·079	1·073	−0·53	Fteley and Stearns.
453	0·5773	6267	1·149	1·166	+1·51	,,
455	0·6725	6125	1·298	1·294	−0·23	,,
456	0·7616	5742	1·423	1·443	+1·40	,,
				Mean	+0·495	

TABLE No. VIII.

Brickwork (rather rough).

$n = 2\ 00$
$C = 0\ 008845$
$x = 0.625$
$y = 0·01224$
$z = 0·50$

Reference Number.	Hydraulic Radius in Feet.	S.	Velocity in ft. per sec.		Error per cent.	Names of Observers.
			Observed.	By Formula.		
20	0·192	480·8	2·75	2·750	0·00	Darcy and Bazin.
21	0·284	,,	3·66	3·554	−2·90	,,
22	0·365	,,	4·18	4·186	+0·14	,,
23	0·424	,,	4·72	4·610	−2·32	,,
24	0·481	,,	5·10	5·008	−1·80	,,
25	0·540	,,	5·33	5·384	+1·02	,,
26	0·582	,,	5·68	5·642	−0·68	,,
27	0·620	,,	6·01	5·870	−2·38	,,
28	0·668	,,	6·15	6·150	0·00	,,
29	0·697	,,	6·47	6·315	−2·39	,,
30	0·739	,,	6·60	6·551	−0·73	,,
31	0·779	,,	6·72	6·770	+0·77	,,
				Mean	−0·94	
Circular sewer ($\frac{1}{4}$th sewage, $\frac{3}{4}$ths sea water.)						
361	1·875	1720·7	3·929	4·038	+2·78	Clarke.
362	,,	1803·1	3·798	3·944	+3·85	,,
363	,,	1947·5	3·769	3·795	+0·70	,,
				Mean	+2·44	

TABLE No. IX.

Unplaned plank.

$n = 2{\cdot}00$
$C = 0{\cdot}008451$
$x = 0{\cdot}615$
$y = 0{\cdot}03349$
$z = 0{\cdot}50$

Rectangular pipe 2·625 feet × 1·64 feet.

Reference Number.	Hydraulic Radius in Feet.	S.	Velocity in Ft. per Second.		Error per cent.	Names of Observers.
			Observed.	By Formula.		
375	0·505	2128·0	1·67	1·685	+0·90	Darcy and Bazin.
376	„	926·0	2·52	2·555	+1·37	„
377	„	526·4	3·35	3·389	+0·56	„
378	„	343·6	4·22	4·194	−0·62	„
379	„	234·2	5·07	5·079	+0·18	„
380	„	197·7	5·53	5·530	0·00	„
381	„	173·6	5·91	5·90	−0·19	„
382	„	151·3	6·37	6·32	−0·78	„
				Mean	+0·177	
Rectangular pipe 1·575 feet × ·984 feet.						
383	0·303	1887·1	1·23	1·265	+2·83	„
384	„	934·8	1·78	1·797	+0·97	„
385	„	578·1	2·28	2·285	+0·24	„
386	„	366·3	2·94	2·871	−2·34	„
387	„	258·4	3·53	3·418	−3·15	„
388	„	159·5	4·35	4·350	0·00	„
389	„	137·6	4·62	4·685	+3·80	„
390	„	113·6	5·31	5·155	−2·93	„
				Mean	−0·077	
Rectangular open channel 6·53 feet wide. Temp. 45° F.						
56	0·240	480·8	2·08	2·134	+2·61	„
58	0·453	„	3·16	3·313	+4·83	„
60	0·601	„	3·78	3·946	+4·38	„
62	0·704	„	4·34	4·350	+0·21	„
64	0·801	„	4·72	4·708	−0·25	„
67	0·922	„	5·21	5·133	−1·46	„
				Mean	+1·72	
Rectangular open channel 6·53 feet wide. Temp. 47° F.						
68	0·188	204·1	2·71	2·758	+1·77	„
70	0·342	„	4·35	4·177	−3·95	„
72	0·453	„	5·29	5·085	−3·86	„
74	0·547	„	5·93	5·716	−3·59	„
76	0·628	„	6·45	6·224	−1·26	„
78	0·698	„	6·90	6·639	−3·78	„
				Mean	−2·445	

Table No. X.

Rectangular open channel 6·01 feet wide.
Small gravel (·03 to ·07 feet diam.) fixed in cement.

Temp. 58° F.

$n = 2{\cdot}00$
$C = 0{\cdot}01181$
$x = 0{\cdot}66$
$y = 0{\cdot}03938$
$z = 0{\cdot}60$

Reference Number.	Hydraulic Radius in Feet.	S.	Velocity in Ft. per Second.		Error per cent.	Names of Observers.
			Observed.	By Formula.		
32	6·250	204·08	2·16	2·160	0·00	Darcy and Bazin.
33	0·357	„	2·95	2·911	−1·33	„
34	0·450	„	3·40	3·380	−0·60	„
35	0·520	„	3·84	3·755	−2·21	„
36	0·588	„	4·14	4·175	+0·86	„
37	0·644	„	4·43	4·434	+0·09	„
38	0·700	„	4·64	4·685	+0·97	„
39	0·746	„	4·88	4·885	+0·12	„
40	0·785	„	5·12	5·049	−1·40	„
41	0·832	„	5·26	5·251	−0·19	„
42	0·871	„	5·43	5·411	−0·35	„
43	0·910	„	5·57	5·570	0·00	„
				Mean	−0·336	

Table No. XI.

Rectangular open channel 6·11 feet wide.
Large gravel (·10 feet to ·13 feet diam.) fixed in cement.

Temp. 59° Fahr.

$n = 2{\cdot}00$
$C = 0{\cdot}01415$
$x = 0{\cdot}705$
$y = 0{\cdot}0759$
$z = 1{\cdot}00$

Reference Number.	Hydraulic Radius in Feet.	S.	Velocity in Ft. per Sec.		Error per cent.	Names of Observers.
			Observed.	By Formula.		
44	·291	204·1	1·79	1·79	0·00	Darcy and Bazin.
45	·417	„	2·43	2·485	+2·26	„
46	·510	„	2·90	2·925	+0·88	„
47	·587	„	3·27	3·285	+0·47	„
48	·656	„	3·56	3·590	+0·86	„
49	·712	„	3·85	3·830	−0·50	„
50	·772	„	4·03	4·078	+1·20	„
51	·823	„	4·23	4·282	+1·25	„
52	·867	„	4·43	4·454	+0·55	„
53	·909	„	4·60	4·614	+0·30	„
54	·946	„	4·78	4·752	−0·58	„
55	·987	„	4·90	4·900	0·00	„
				Mean	+0·557	

Table No. XII.

Hammer-dressed masonry (not very rough). $n = 2{\cdot}00$, $C = 1{\cdot}011166$, $x = 0{\cdot}66$, $y = 0{\cdot}07825$, $z = 1{\cdot}00$

Open channel nearly rectangular, 6·2 feet wide.

Reference Number.	Hydraulic Radius in Feet.	S.	Velocity in Ft. per Sec.		Error per cent.	Names of Observers.
			Observed.	By Formula.		
351	0·98	3279	1·32	1·543	+16·92	Darcy and Bazin.
352	1·29	3247	1·90	1·859	− 2·19	„
353	1·49	3021	2·12	2·120	0·00	
354	1·60	2882	2·47	2·275	− 7·89	
				Mean	+ 1·71	
Open channel similar to last, 5·91 feet wide (with some adhering slime). Temp. 64° Fahr.						
301	0·424	27·03	9·04	9·04	0·00	„
302	0·620	„	11·46	11·926	+ 4·11	„
303	0·745	„	13·55	13·674	+ 0·93	„
304	0·852	„	15·08	15·063	− 0·11	„
				Mean	+ 1·23	
Same as last. Temp. 64° Fahr.						
297	0·324	9·90	12·29	11·899	− 3·17	„
298	0·467	„	16·18	16·077	− 0·65	„
299	0·580	„	18·68	19·156	+ 2·54	„
300	0·662	„	21·09	21·184	+ 0·47	„
				Mean	- 0·20	

Table No. XIII.

Rectangular open channel 6·43 feet wide. Wood with laths ·09 feet by ·03 feet, nailed ·03 feet apart at right angles to the direction of the flow. Temp. 46° F. $n = 2{\cdot}00$, $C = 0{\cdot}009684$, $x = 0{\cdot}636$, $y = 0{\cdot}068$, $z = 1{\cdot}00$

Reference Number.	Hydraulic Radius in Feet.	S.	Velocity in Ft. per Sec.		Error per cent.	Names of Observers.
			Observed.	By Formula.		
113	·302	666·7	1·65	1·651	+0·05	Darcy and Bazin.
114	·442	„	2·17	2·185	+0·72	„
115	·632	„	2·86	2·917	+2·00	„
116	·775	„	3·33	3·370	+1·20	„
117	·889	„	3·68	3·700	+0·56	„
118	·986	„	3·98	3·964	−0·39	„
119	1·076	„	4·19	4·19	0·00	„
				Mean	+0·59	

Table No. XIV.

Same as in Table XIII., but with laths ·16 feet apart.

Temp. 59° F.

$n = 2·00$
$C = 0·014506$
$x = 0·71$
$y = 0·0358$
$z = 1·00$

Reference Number.	Hydraulic Radius in Feet.	S.	Velocity in Ft. per Sec.		Error per cent.	Names of Observers.
			Observed.	By Formula.		
134	·378	666·7	1·28	1·280	0·00	Darcy and Bazin.
135	·550	„	1·68	1·715	+2·10	„
136	·777	„	2·21	2·224	+0·52	„
137	·942	„	2·55	2·545	−0·18	„
138	1·073	„	2·81	2·810	0·00	„
139	1·197	„	2·97	3·037	+2·37	„
140	1·299	„	3·11	3·218	+3·50	„
				Mean	+1·17	

Table No. XV.

Open channels
" Earth no vegetation," &c.

$n = 2·00$
$C = 0·015356$
$x = 0·72$

Reference Number.	Hydraulic radius in feet.	S.	Velocity in feet per sec.		Error per cent.	Names of Observers.
			Observed.	By formula.		
367	0·96	4000	0·89	1·00	+12·3	Darcy & Bazin.
368	1·32	3636	1·34	1·318	− 1·5	„
369	1·57	4066	1·36	1·410	+ 3·6	„
370	1·78	3636	1·67	1·635	− 2·1	„
7	2·871	2326	2·54	2·90	+14·0	Baumgarten.
Ganges Canal	4·10	4878	2·70	2·57	− 4·0	Cunningham.
" Solani right "	5·00	4166	3·40	3·21	− 5·5	„
	6·10	4545	3·70	3·55	− 4·0	„
	8·00	5263	4·10	4·01	− 2·2	„
478	6·721	10720	2·515	2·48	− 1·3	Ellet.
472	15·706	2238	3·076	3·162	+ 2·7	Humphreys and Abbot.
473	13·039	2681	2·843	2·527	−11·1	
474	12·801	2736	2·807	2·468	−12·0	„
475	12·470	2281	2·789	2·652	− 4·9	„
Great Nevka	17·418	67250	2·0486	1·965	− 4·07	Destrem.
460	72·03	48760	5·929	6·414	+ 8·1	Humphreys and Abbot.
461	72·46	58380	5·887	5·887	0·0	
				Mean	−0·704	

TABLE No. XVI.

Rough stony earth.

$n = 2{\cdot}00$
$C = 0{\cdot}021444$
$x = 0{\cdot}78$

	Hydraulic Radius in Feet.	S.	Velocity in Ft. per Second.		Error per cent.	Name of Observer.
			Observed.	By Formula.		
	2·25	6,758	0·87	1·068	+22·71	Cunningham.
Ganges	3·90	11,366	1·35	1·264	− 6·35	„
Canal	4·80	4,894	1·90	2·266	+19·26	„
"Solani	5·70	6,211	2·50	2·300	− 8·00	„
Main."	6·20	5,849	3·00	2·530	−15·64	„
	7·70	4,673	3·30	3·321	+ 0·65	„
	8·90	4,406	3·70	3·865	+ 4·45	„
	9·30	4,406	4·00	4·000	0·00	„
				Mean	+2·26	

TABLE No. XVIII.

Friction of water at various temperatures, the friction at 60° F. being taken as 100·00.

Temp.	Mair.	Hagen.	Unwin.	Temp.	Mair.	Unwin.
deg. F.				deg. F.		
36·5	..	112·21		67	97·43	98·45
37	..	111·95		68	97·07	98·23
38	..	111·43		69	96·70	98·01
39	..	110·91		70	96·33	97·79
40	..	110·39		72	95·89	97·47
41	..	109·87	107·59	74	95·45	97·15
42	..	109·35	107·06	76	95·02	96·83
43	..	108·83	106·55	78	94·57	96·51
44	..	108·31	106·04	80	94·14	96·19
45	..	107·79	105·53	82	93·62	95·87
46	..	107·27	105·01	84	93·11	95·55
47	..	106·75	104·50	86	92·60	95·23
48	..	106·23	103·98	88	92·08	94·91
49	..	105·71	103·47	90	91·57	94·59
50	..	105·19	102·95	92	91·13	94·27
51	..	104·67	102·44	94	90·68	93·95
52	..	104·15	101·92	96	90·25	93·63
53	..	103·63	101·41	98	89·81	93·31
54	..	103·11	101·20	100	89·37	92·99
55	..	102·60	101·00	105	87·72	92·20
56	..	102·08	100·80	110	86·08	91·40
57	101·09	101·56	100·60	115	84·98	90·60
58	100·73	101·04	100·40	120	83·88	89·80
59	100·36	100·52	100·20	125	83·14	89·00
60	100·00	100·00	100·00	130	82·41	88·20
61	99·63	99·48	99·77	135	81·25	
62	99·26	98·96	99·55	140	80·09	
63	98·90	98·44	99·33	145	78·45	
64	98·53		99·11	150	77·29	
65	98·16		98·89	160	75·45	
66	97·80		98·67			

NOTE.—The above figures are deduced from results given by Mair in Proc. Inst. C.E., vol. lxxxiv. p. 431; Unwin, 'The Engineer,' Jan. 1, 1886; Hagen, 'Das Handbuch der Wasserbaukunst,' vol. i. p. 222.

TABLE No. XVII.

Summary of Coefficients given in Tables I. to XVI.

Description of Surface.	n	c.	x.	y.	z.	
Wrought-iron pipes	1·80	0·004787	0·65	0·018	0·07	See Table I.
Riveted sheet-iron pipes	1·825	0·005674	0·677	?	?	„ II.
New cast-iron pipes A	1·85	0·005347	0·67	?	?	„ III.
„ „ B	2·00	0·006752	0·63	?	?	„ „
Lead pipes	1·75	0·005224	0·62	?	?	„ IV.
Pure cement rendering	1·74	0·004000	0·67	?	?	„ V.
„ „	1·95	0·006429	0·61	?	?	„ VI.
Brickwork (in good condition)	2·00	0·007746	0·61	?	?	„ VII.
„ (rather rough)	2·00	0·008845	0·625	0·01224	0·50	„ VIII.
Unplaned plank	2·00	0·008451	0·615	0·03349	0·50	„ IX.
Small gravel fixed in cement	2·00	0·01181	0·66	0·03938	0·60	„ X.
Large „ „	2·00	0·01415	0·705	0·07590	1·00	„ XI.
Hammer-dressed masonry	2·00	0·011166	0·66	0·07825	1·00	„ XII.
Laths 0.09 feet × 0·03 feet, nailed 0·03 feet apart	2·00	0·009684	0·636	0·0680	1·00	„ XIII.
„ „ „ 0·16 „	2·00	0·014506	0·71	0·0358	1·00	„ XIV.
Earth (no vegetation), &c.	2·00	0·015356	0·72	?	?	„ XV.
Rough stony earth	2·00	0·021444	0·78	?	?	„ XVI.

Table No. XIX.

Reference List of Pipe Experiments.

Reference Numbers.		Diameter of Pipe.	Material.	Authority.	Number of Table giving Details.
On Diagram No. 1.	In Hamilton Smith's 'Hydraulics.'				
1	..	0·242 inch..	Lead	Osborne Reynolds	IV.
2	65–77	0·0122 metre	Drawn iron	Darcy	
2A	..	0·49 inch ..	Sheet iron	Thrupp	I.
3	..	0·498 „ ..	Lead	Osborne Reynolds	IV.
4	110–116	0·014 metre	„	Darcy	„
4A	..	0·62 inch ..	Wrought iron (gas)	Girard	
5	131–142	0·0268 metre	Sheet iron	Darcy	I.
6	78–90	0·0266 „	Drawn iron	„	
7	117–123	0·0270 „	Lead	„	IV.
8	179–185	0·0359 „	Old cast iron	„	
9	186–192	0·0364 „	No. 8, cleaned ..	„	
10	124–130	0·041 „	Lead	„	IV.
11	98–109	0·0395 „	Drawn iron	„	
12	173–178	0·0498 „	Glass	„	
13	..	2½ inch ..	Lead	James Leslie ..	IV.
14	193–198	0·0795 metre	Old cast iron	Darcy	
15	199–205	0·0801 „	No. 14, cleaned ..	„	
16	206–218	0·0819 „	New cast iron.. ..	„	III.
17	143–154	0·0826 „	Sheet iron	„	I.
18	..	0·4441 feet	Cast iron	Couplet	
19	219–228	0·137 metre	New cast iron ..	Darcy	III.
20	229–237	0·188 „	„	„	„
21	155–165	0·196 „	Sheet iron	„	I.
21A	..	0·200 „	Wrought iron.. ..	Stockalper	
22	238–245	0·2432 „	Old cast iron	Darcy	
23	..	0·25 „	Cast iron..	Arson	
24	246–253	0·2447 „	No. 22, cleaned ..	Darcy	
25	..	10 inch ..	Cast iron..	Clegg (?)	
26	340–344	0·911 ft. ..	Riveted sheet iron	Hamilton Smith	II.
27	166–172	0·285 metre	Sheet iron	Darcy	I.
28	254–261	0·297 „	{Old cast iron, well cleaned .. ..}	„	
29	345–348	1·056 ft. ..	Riveted sheet iron..	Hamilton Smith	II.
30	349–354	1·23 „ ..	„ ..	„ ..	„
31	..	1·33 „ ..	„ ..	„ ..	
31A	275–278	1·373 „ ..	New cast iron ..	Lampe	III.
32	262–270	0·50 metre	„ ..	Darcy	„
33	..	26 inch ..	Cast iron..	Clegg (?)	
34	..	30 „ ..	„	Darrach	
35	282–285	48 „ ..	„	Stearns	
	356	1·416 ft. ..	Riveted sheet iron..	Hamilton Smith	II.
	286	2·43 „ ..	„ ..	„	„
375–382	375–382	Rectangular	Unplaned plank ..	Darcy and Bazin	IX.
383–390	383–390	„	„ ..	„	„
..	361–363	7·5 ft. diam.	Brickwork	Clarke	VIII.

Notes.—No. 4A represents results of experiments with gas and air.
No. 21A „ „ „ compressed air.
Nos. 23, 25, and 33 represent results of experiments with gas.

TABLE No. XX.

Reference list of Open Channel Experiments.

Reference Numbers on Diagrams and in Hamilton Smith's 'Hydraulics.'	Diagrams Showing Results.	Description of Channel.	Authority.	Number of Table giving Details.
8–19	Nos. I. & III.	Pure cement	Darcy and Bazin	VI.
20–31	No. III.	Brickwork	„	VIII.
32–43	„	Small gravel in cement	„	X.
44–55	Nos. I. & III.	Large ditto	„	XI.
56–67	„	Unplaned plank ..	„	IX.
68–79	„	„ „ ..	„	„
80–91	No. III.	„ „ ..	„	
106–112	„	„ „ ..	„	
113–119	Nos. I. & III.	Laths nailed across	„	XIII.
127–133	No. 5	„	„	
134–140	„	„	„	XIV.
141–147	„	„	„	
148–154	„	„	„	
155–166	„	Unplaned plank ..	„	
167–177	„	„ ..	„	
178–186	„	„ ..	„	
187–198	„	„ ..	„	
199–210	„	„ ..	„	
223–234	„	Pure cement	„	V.
235–246	„	Cement and ⅓rd sand	„	
247–259	„	Partly planed plank	„	
260–269	„	Small gravel in cement	„	
270–276	„	Smooth wood	„	
277–281	„	„	„	
282–287	„	Cloth	„	
288–296	„	„	„	
297–300	„	Hammer-dressed masonry	„	XII.
301–304	„	„ ..	„	
305–309		Dry hammer-dressed		
310–314	„	masonry	„	
315–318	No. I.	Earth with weeds ..	„	
319–322	„	„ stony, few weeds	„	
323–326	„	„	„	
335–338	„	„	„	
343–346	„	„ with weeds ..	„	
351–354	„	Masonry	„	XII.
355–358	„	„	„	
359–362	„	Earth with weeds ..	„	
363–366	„	„ ..	„	
367–370	„	„ no weeds ..	„	XV.
371–374	„	„ with weeds ..	„	
391, &c.	Nos. I. & III.	Brickwork	Fteley and Stearns	VII.
451, &c.	No. I.	„	„	„
443–445	„	Pure cement	„	VI.
460–461	„	Mississipi	Humphreys and Abbot	XV.
468–469	„	„	„	
472–475	„	„	„	XV.
478	„	Ohio	Ellet	„
..	„	Ganges canal	Cunningham ..	XV. and XVI.

Obituary.

Sir Joseph Whitworth was born at Stockport on December 21st, 1803, and died on the night of Saturday, January 22nd, 1887, at Monte Carlo, in his eighty-fourth year. After having been partially educated at home, he was sent to school at Idle, near Leeds, but at the age of fourteen he was placed with his uncle, a cotton-spinner in Derbyshire. Having in four years learned all he could there, he left for Manchester, where four years more were spent in acquiring a practical knowledge of the manufacture of cotton-spinning machinery in the shops of Crighton, Marsden, Walker, and others. At the age of twenty-two he left Manchester for London and passed eight years in the shops of Maudslay, Holtzapfel, Wright, and Clements respectively. It was while at Maudslay's that he conceived and executed the idea of his celebrated true planes which have proved such great factors in the advancement of accurate mechanical construction.

In 1833, having acquired all the experience he could in the best shops in London, Whitworth returned to Manchester, and commenced business as a manufacturer of engineers' tools. Here his standard gauges, his taps and dies, his uniform system of screw threads, his great refinements in the manufacture of lathes, planing machines, and drills, soon gained for him a reputation, and exerted an influence abroad in other directions. From 1833 to 1851 Whitworth worked steadily in this direction, appearing in the Great Exhibition at Hyde Park as a maker of engineers' tools, and showing, as his best credentials in that respect, the true plane and the measuring machine indicating to the millionth of an inch. In 1853 Mr. Whitworth went to America, as one of the Royal Commissioners to the New York Exhibition, and in that capacity he drew up a special report on American manufacturing industry, which attracted much attention at the time, and still has considerable interest. On his return home, he began to study the principles of construction underlying the manufacture of rifles and rifled artillery. His investigations were of the utmost importance and interest, and the conclusions he arrived at have worked a complete revolution in the manufacture of arms of precision, for all modern rifles, whatever name they may bear, are substantially founded on his demonstration, that an elongated projectile (from three

to five diameters), with a rapid rotation and a quick uniform rifling pitch of polygonal form, was the true form for accurate firing. This was true not only for small arms, but, with modifications, for all sizes of ordnance. Having worked out the principles upon which rifled small arms and ordnance should be constructed, Mr. Whitworth found himself face to face with the difficult question of a proper material for their manufacture. This ultimately led to the production of that splendid metal known as Whitworth fluid compressed steel, in which the important qualities of strength, ductility, and homogeneity co-exist in an extraordinary degree..

In 1857 Mr. Whitworth was made a Fellow of the Royal Society, LL.D. of Trinity College, Dublin, and D.C.L. of Oxford University. At the Paris Universal Exhibition of 1867 he took for his fine collection of engineers' tools and rifled ordnance and projectiles one of the five "Grand Prix" allotted to England, and during the visit of the late Emperor of the French to the camp at Chalons in September 1868, he was so pleased with one of the Whitworth field guns tried there, that he conferred upon the inventor the distinction of the Legion of Honour. The Albert Gold Medal was also awarded to Mr. Whitworth by the Council of the Society of Arts "for the invention and manufacture of instruments of measurement and uniform standards, by which the production of machinery has been brought to a degree of perfection hitherto unapproached." In 1869 Mr. Whitworth was created a baronet. Early in that year he had founded and endowed the Whitworth Scholarships, assigning for the purpose 3000*l.* a year in perpetuity, that being the interest on a capital sum of 100,000*l*, and large sums under his will were devoted to the promotion of higher education among such children in humble life as show proof of natural ability and industry.

Sir Joseph had been for twenty years an Honorary Member of the Society of Engineers.

Mr. M. Ogle Tarbotton was born in 1834, and died on the 6th March, 1887. He was articled in 1849, and afterwards became Engineer to the Corporation of Wakefield. He was afterwards for twenty-one years Chief Engineer to the Corporation of Nottingham. On the Corporation taking over the gas and water supplies of Nottingham, Mr. Tarbotton gave up the office of Borough Engineer and was appointed Engineer to the Gas and Water Committee and Consulting Engineer to the Corporation. He acquired a reputation in matters connected with gas, water, and sewage, and his death was the result of overwork of brain and nervous prostration.

Mr. Tarbotton was, at the time of his death, a Vice-President of the Society of Engineers.

SOCIETY OF ENGINEERS.

INDEX TO TRANSACTIONS.

1861 to 1886.

AUTHORS.

Author.	Subject of Paper.	Published. Year.	Page.
A.			
Abel, C. D.	The Patent Laws	1865	25
Adams, J. H.	President's Address	1875	1
Adams, T.	The Friction of the Slide-valve, and its Appendages.	1866	6
Adams, W.	President's Address	1870	1
Alford, C. J.	The Mineralogy of the Island of Sardinia.	1879	93
„ „	Appendix to Above: Laws relating to Mining.	1879	106
„ „	Engineering Notes on Cyprus	1880	131
Alford, R. F.	The Fell Engines on the Rimutakai Incline, New Zealand.	1882	121
Anderson, Chris. ..	The Feasibility and Construction of Deep-sea Lighthouses.	1883	45
André, G. G.	The Ventilation of Coal Mines	1874	23
„ „	The Application of Electricity to the Ignition of Blasting Charges.	1878	123
Andrews, T.	The Strength of Wrought-iron Railway Axles.	1879	143
Atkinson, J.	Apparatus for Utilising the Waste-heat of Exhaust Steam.	1878	167
B.			
Baldwin, T.	Single and Double Riveted Joints ..	1866	150
„ „	Experimental Researches into the Nature and Action of Safety Valves for Steam Boilers, &c.	1867	23
Bamber, H. K.	Water, and its Effects on Steam Boilers.	1867	65
Barker, C. M.	The Prevention of Leakage in Gas and Water Mains.	1869	79
Barker, E. D.	Hydraulic Continuous and Automatic Brakes.	1879	75
Barker, Capt. W. B.	International System of Marine Course Signalling.	1884	47
Barnett, S., junr. ..	The Value of Exhibitions as Aids to Engineering Progress.	1883	75
Bartholomew, E. G.	Electric Telegraphy, irrespective of Telegraphic Apparatus.	1869	55
„ „	Electric Telegraph Instruments ..	1872	53
„ „	Electrical Batteries	1872	77

Author.	Subject of Paper.	Published. Year.	Page.
Beaumont, W. W. ..	Modern Steel as a Structural Material	1880	109
Behr, F. B.	The Lartigue Single-rail Railway ..	1886	163
Bellasis, E. S.	The Roorkee Hydraulic Experiments	1886	41
Bernays, J.	President's Address	1880	1
„ „	The New Pits and Hauling Machinery for the San Domingos Mines in Portugal.	1879	29
Biggs, C. H. W., and Beaumont, W. W.	Notes on Electric Light Engineering	1882	23
Björling, P. B.	Direct-acting Pumping Engines ..	1877	79
Blackbourn, J.	The Action of Marine Worms and Remedies applied in the Harbour of San Francisco.	1874	111
Bower, G.	The Preservation and Ornamentation of Iron and Steel Surfaces.	1883	59
Bryant, F. W.	President's Address	1869	1
Buckham, T.	The Drainage and Water Supply to the Town of Fareham.	1869	41
C.			
Cargill, T.	President's Address	1877	1
„ „	Railway Bridge at the Place de l'Europe, Paris.	1866	191
„ „	Floating Breakwaters	1871	146
Carrington, W. T. ..	President's Address	1865	1
Carter, J. H.	Roller-milling Machinery	1883	125
Church, Jabez	President's Address	1872	1
„ „	President's Address	1873	1
Church, Jabez, junr. ..	President's Address	1882	1
„ „	President's Address	1883	1
Colam, W. N.	Cable Tramways	1885	69
Colburn, Zerah ..	President's Address	1866	1
„ „	The Relation between the Safe Load and Ultimate Strength of Iron.	1863	35
„ „	Certain Methods of Treating Cast Iron in the Foundry.	1865	77
Conradi, H.	Stone-sawing Machinery	1876	135
Copland, H. S.	Modern Roadway Construction	1878	61
Cox, S. H.	Recent Improvements in Tin-dressing Machinery.	1874	11
Cramp, C. C.	Tramway Rolling-stock and Steam in connection therewith.	1874	119
Crompton, E. S.	The Economics of Railway Maintenance.	1870	101
Cullen, Dr. E.	The Surveys of Proposed Lines for a Ship Canal between the Atlantic and Pacific Oceans.	1868	15
„ „	The Panama Railroad	1868	39
„ „	The Isthmus of Darien and the Ship Canal.	1868	52

Author.	Subject of Paper.	Published. Year.	Page.
D.			
Danvers, F. C.	Engineering in India	1868	137
Davey, H.	Pumping Engines for Town Water-supply.	1867	88
„ „	Milford Haven and its New Pier Work.	1872	89
„ „	Recent Improvements in Pumping Engines for Mines.	1873	182
„ „	The Underground Pumping Machinery at the Erin Colliery, Westphalia.	1876	119
Day, St. J. V.	Recent Arrangements of Continuous Brakes.	1875	87
E.			
Edwards, E.	Utilisation of Waste Mineral Substances.	1861	82
Engert, A. C.	The Prevention of Smoke	1881	101
„ „	Defects of Steam Boilers and their Remedy.	1884	25
„ „	The Blow-pipe Flame Furnace	1884	185
F.			
Faija, H.	Portland Cement	1885	95
Fell, J. C.	Soft *v.* Hard Water for Manufacturing Purposes.	1884	103
Ferrar, W. G.	Practical Construction in the Colonies	1875	53
Fox, St. G. Lane ..	The Lighting and Extinction of Street Gas Lamps by Electricity.	1878	105
Fox, W. H.	Continuous Railway Brakes	1872	112
„ „	Continuous Railway Brakes	1873	33
Fraser, A.	The Use of the Cornish Pumping Engine.	1864	78
G.			
Gandon, C.	President's Address	1885	1
„	Gas Engines	1881	27
Gibbs, J. D.	The Distribution of Electrical Energy by Secondary Generators.	1885	49
Gore, H.	Modern Gas Works at Home and Abroad.	1868	233
„	Horse Railways and Street Tramways	1873	113
Graham, J.	The most recent Improvements on the Injector.	1867	266
Greig, A.	Dundee Street Improvements and Drainage of Lochee.	1883	113
Gresham, J.	The most Recent Improvements on the Injector.	1867	266
Grierson, F. W. ..	The National Value of Cheap Patents	1880	145

Author.	Subject of Paper.	Published. Year.	Page.
H.			
Hakewill, H.	Circular Tables	1865	147
Hall, C. E.	The Conversion of Peat into Fuel and Charcoal.	1876	151
„ „	Modern Machinery for preparing Macadam for Roads.	1879	51
Hartley, F. W. ..	Methods employed in the Determination of the Commercial Value and the Purity of Coal Gas.	1869	100
„ „	An Improved Method of Charging and Drawing Gas Retorts.	1875	185
Horner, J. G.	Certain methods of applying Screw Piles in a Bridge at Verona.	1867	52
Horsley, C.	President's Address	1881	1
J.			
Jacob, A.	The Designing and Construction of Storage Reservoirs.	1866	225
Jensen, P.	Incrustation in Marine Boilers	1866	117
„ „	Friction in Steam Cylinders	1870	17
Jerram, G. B.	River Pollution caused by Sewage Disposal.	1886	217
Jones, A. W.	Modern Tramway Construction	1879	179
Justice, P. S.	The Dephosphorisation of Iron in the Puddling Furnace.	1885	189
K.			
King, G.	Irrigation with Town Sewage	1865	84
Kinsey, W. B.	The Arrangement, Construction, and Machinery of Breweries.	1881	173
Knapp, H. F.	Harbour Bars: their Formation and Removal.	1878	139
Kochs, W. E.	Strength and Rigidity	1865	69
L.			
Latham, B.	President's Address	1868	1
„ „	President's Address	1871	1
„ „	The Drainage of the Fens	1862	154
„ „	The Inundations of Marsh Lands ..	1862	173
„ „	The Supply of Water to Towns ..	1864	199
„ „	Utilisation of Sewage	1866	68
„ „	The Application of Steam to the Cultivation of the Soil.	1868	274
„ „	Ventilation of Sewers	1871	39
Le Feuvre, W. H. ..	President's Address	1867	1
Le Grand, A.	Tube Wells	1877	133
Light, C. J.	The Need of further Experiments on the Strength of Materials.	1869	194
„ „	A new Method of setting-out the Slopes of Earthworks.	1873	216
„ „	Opening Bridges on the Furness Railway.	1885	119
Louch, J.	Surface Condensers	1861	96

Author.	Subject of Paper.	Published. Year.	Page.
M.			
MACGEORGE, W.	President's Address	1874	1
MAJOR, W.	The Priming of Steam-Boilers	1877	59
MARTIN, W.	The Strength of Flues in Lancashire and similar Boilers.	1882	157
MARTIN, W. A.	Induced *v.* Forced Draught for Marine Boilers.	1886	111
MATHESON, E.	The Quality of Iron, as now used ..	1867	168
„ „	The Accumulator Cotton Press	1868	264
MAUDE, T.	The Government Brake Trials	1875	129
MCNAUGHT, W.	The Rolling of Ships	1876	187
MOORE, L. G.	The Explosion at Erith, and the Repair of the River bank.	1864	183
N.			
NURSEY, P. F.	President's Address	1886	1
„ „	The Superheating of Steam, and the various apparatus employed therein.	1861	36
„ „	Steam Boiler Explosions	1863	1
„ „	Fuel	1864	1
„ „	Sugar-making Machinery	1865	155
„ „	Explosive Compounds for Engineering Purposes.	1869	10
„ „	English and Continental Intercommunication.	1869	154
„ „	Recent Improvements in Explosive Compounds.	1871	108
„ „	Economic Uses of Blast Furnace Slag	1873	196
„ „	Mechanical Puddling	1874	77
„ „	The Channel Railway	1876	17
„ „	Illumination by means of Compressed Gas.	1881	57
„ „	Modern Bronze Alloys for Engineering Purposes.	1884	127
O.			
OATES, A.	The Utilisation of Tidal Energy ..	1882	81
OLANDER, E.	The Enclosure of Lands from the Sea, and the Construction of Sea and other Banks.	1862	25
OLRICK, H.	A new System of Treating Sewage Matter.	1883	23
OLRICK, L.	Marine Governors	1862	104
„ „	Giffard's Injector	1865	280

Author.	Subject of Paper.	Published. Year.	Page.
P.			
PAGE, G. G.	The Construction of Chelsea Bridge..	1863	77
PARKES, M.	The Road Bridges of the Charing Cross Railway.	1864	143
„ „	The Charing Cross Railway Bridge over the Thames.	1864	166
PARSEY, W.	Trussed Beams	1862	52
PEARSE, J. W.	The Ventilation of Buildings	1876	97
„ „	The Mechanical Firing of Steam Boilers.	1877	31
„ „	Water Purification, Sanitary and Industrial.	1878	29
PENDRED, H. W.	Screw Propellers, their Shafts and Fittings.	1875	151
„ „	Distilling and Hoisting Machinery for Sea-going Vessels.	1880	55
„ „	Designs, Specifications and Inspection of Ironwork.	1883	87
PENDRED, V.	President's Address	1876	1
„ „	Elastic Railway Wheels	1864	119
„ „	The Adhesion of Locomotive Engines, and certain Expedients for increasing or supplementing that Function.	1865	207
„ „	Water-tube Boilers	1867	109
„ „	Apparatus for Measuring the Velocity of Ships.	1869	215
„ „	Examples of Recent Practice in American Locomotive Engineering.	1872	19
PHILLIPS, J.	The Forms and Construction of Channels for the Conveyance of Sewage.	1874	145
PIEPER, C.	Ice-making Machinery	1882	139
R.			
READE, S. A.	The Redhill Sewage Works	1868	168
REDMAN, J. B.	Tidal Approaches and Deep-water Entrances.	1885	143
RIGG, A.	President's Address	1884	1
„ „	The Connection between the Shape of heavy Guns and their Durability.	1867	249
„ „	The Screw Propeller	1868	202
„ „	Sensitiveness and Isochronism in Governors.	1880	73
„ „	American Engineering Enterprise ..	1885	21
„ „	Obscure Influences of Reciprocation in High-speed Engines.	1886	83
RILEY, E.	The Action of Peaty Water on a Boiler	1862	45
„ „	The Manufacture of Iron	1861	59
ROBERTS, W . ..	Steam Fire-engines, and the late Trials at the Crystal Palace.	1863	163
ROBINSON, H. . ..	Sewage Disposal	1879	197
RUMBLE, T. W.	Armour Plates	1861	87
RYMER-JONES, T. M. .	Railway Tunnelling in Japan	1882	101

Author.	Subject of Paper.	Published. Year.	Page.
S.			
SANDERSON, C.	The Bombay, Baroda, and Central India Railway.	1863	97
SEFI, M.	The Theory of Screw Propulsion ..	1870	82
SOMERVILLE, J.	Charging and drawing Gas Retorts by Machinery.	1873	138
SPENCER, G.	State Railways and Railway Amalgamation.	1872	43
SPICE, R. P.	President's Address	1878	1
„ „	President's Address	1879	1
„ „	Some Modern Improvements in the Manufacture of Coal Gas.	1886	131
SPON, E.	The Use of Paints as an Engineering Material.	1875	69
STANDFIELD, J.	Floating Docks—the Depositing Dock, and the Double-power Dock.	1881	81
STEEL, J.	Air Compression	1876	65
STEPHENSON, W. H. ..	Fire-clay Manufactures	1861	17
STOPES, H.	The Engineering of Malting	1884	65
SUCKLING, N. J.	Modern Systems of Generating Steam	1874	39
SUGG, W.	Apparatus employed for Illumination with Coal Gas.	1869	134
SUTCLIFF, R.	Tube Wells for large Water Supplies	1877	149
SCHÖNHEYDER, W. ..	Equalising the wear in Horizontal Steam Cylinders.	1878	45
T.			
TARBUTT, P. F.	Liquid Fuel	1886	193
TREWMAN, H. C.	Flues and Ventilation	1876	91
TURNER, C.	The Timbering of Trenches and Tunnels.	1871	90
TWEDDELL, R. H. ..	Direct-Acting Hydraulic Machinery ..	1877	95
U.			
USILL, G. W.	Rural Sanitation	1877	113
V.			
VARLEY, S. A.	Railway Train Intercommunication ..	1873	162
W.			
WALMISLEY, A. T. ..	Iron Roofs	1881	123
WANKLYN, J. A.	Cooper's Coal-liming Process	1884	167
WARD, G. M.	The Utilisation of Coal Slack in the Manufacture of Coke for Smelting.	1880	33
WALKER, J.	Brewing Apparatus	1871	29
WARREN, A.	Steam Navigation on the Indus ..	1863	139
WESSELY, C. R. VON ..	Arched Roofs	1866	36
WILKINS, T.	The Machinery and Utensils of a Brewery.	1871	10

Author.	Subject of Paper.	Published.	
		Year.	Page.
Wilson, A. F.	The Manufacture of Coal Gas	1864	35
Wilson, J. W., junr. ..	The Construction of Modern Piers ..	1875	29
Wise, F.	Signalling for Land or Naval Purposes.	1863	117
Wise, W. L.	The Patent Laws	1870	45
Worssam, S. W., junr.	Mechanical Saws	1867	196
Y.			
Yarrow, A. F.	Steam Carriages	1862	128
Young, C. F. T.	The Use of Coal in Furnaces without Smoke.	1862	66

SUBJECTS.

Subject of Paper.	Author.	Published. Year.	Page.
A.			
Accumulator Cotton Press	E. Matheson	1868	264
Action of Peaty Water on a Boiler ..	E. Riley	1862	45
Action of Marine Worms and Remedies employed in the Harbour of San Francisco.	J. Blackbourn	1874	111
Address of President	W. T. Carrington ..	1865	1
„ „	Z. Colburn	1866	1
„ „	W. H. Le Feuvre ..	1867	1
„ „	B. Latham	1868	1
„ „	F. W. Bryant	1869	1
„ „	W. Adams	1870	1
„ „	B. Latham	1871	1
„ „	J. Church	1872	1
„ „	„ „	1873	1
„ „	W. Macgeorge	1874	1
„ „	J. H. Adams	1875	1
„ „	V. Pendred	1876	1
„ „	T Cargill	1877	1
„ „	R. P. Spice	1878	1
„ „	„ „	1879	1
„ „	J. Bernays	1880	1
„ „	C. Horsley	1881	1
„ „	J. Church	1882	1
„ „	„ „	1883	1
„ „	A. Rigg	1884	1
„ „	C. Gandon	1885	1
„ „	P. F. Nursey	1886	1
Adhesion of Locomotive Engines and certain Expedients for Increasing or Supplementing that Function.	V. Pendred	1865	207
Air Compression	J. Steel	1876	65
American Engineering Enterprise ..	A. Rigg	1885	21
American Locomotive Engineering, Examples of recent Practice in	V. Pendred	1872	19
Apparatus for utilising the Waste Heat of Exhaust Steam.	J. Atkinson	1878	167
Apparatus for Measuring the Velocity of Ships.	V. Pendred	1869	15
Apparatus employed for Illumination with Coal Gas.	W. Sugg	1869	134
Application of Steam to the Cultivation of the Soil.	B. Latham	1868	274

Subject of Paper.	Author.	Published. Year.	Page.
Arched Roofs	C. von Wessely	1866	36
Armour Plates	T. W. Rumble	1861	87
Arrangement, Construction and Machinery of Breweries.	W. B. Kinsey	1881	173
Axles, The Strength of Wrought-iron Railway	T. Andrews	1879	143
B.			
Blast-furnace Slag, The Economic Uses of	P. F. Nursey	1873	196
Blasting Charges, The Application of Electricity to the Ignition of	G. G. André	1878	123
Blow-pipe Flame Furnace	A. C. Engert	1884	185
Boilers, Incrustation in Marine	P. Jensen	1866	117
Boilers, Strength of Flues in Lancashire and similar	W. Martin	1882	157
Boilers, The Defects of Steam, and their Remedy.	A. C. Engert	1884	25
Boilers, The Mechanical Firing of Steam	J. W. Pearse	1877	31
Boilers, The Priming of Steam	W. Major	1877	59
Boilers, Water and its Effects on Steam	H. K. Bamber	1867	65
Boilers, Water Tube	V. Pendred	1867	109
Bombay, Baroda and Central India Railway.	C. Sanderson	1863	97
Brake Trials, The Government	T. Maude	1875	129
Brakes, Continuous Railway	W. H. Fox	1872	112
" "	" "	1873	33
Brakes, Hydraulic Continuous and Automatic.	E. D. Barker	1879	75
Brakes, Recent Arrangements of Continuous	St. J. V. Day	1875	87
Breakwaters, Floating	T. Cargill	1871	146
Breweries, the Arrangement, Construction, and Machinery of	W. B. Kinsey	1881	173
Brewery, Machinery and Utensils of a	T. Wilkins	1871	10
Brewing Apparatus	J. Walker	1871	29
Bridge, Railway, at the Place de l'Europe, Paris.	T. Cargill	1866	191
Bridge, Construction of Chelsea	G. G. Page	1863	77
Bridge over the Thames, Charing Cross Railway	M. Parkes	1864	166
Bridges of the Charing Cross Railway, The Road	" "	1864	143
Bridges, Opening, on the Furness Railway.	C. J. Light	1885	119
Bronze Alloys for Engineering Purposes, Modern	P. F. Nursey	1884	127
Buildings, The Ventilation of	J. W. Pearse	1876	97

Subject of Paper.	Author.	Published. Year.	Page.
C.			
Cable Tramways	W. N. Colam	1885	69
Canal between the Atlantic and Pacific Oceans, The Surveys of Proposed Lines for a Ship	Dr. E. Cullen	1868	15
Canal, The Isthmus of Darien and the Ship	„ „	1868	52
Carriages, Steam	A. F. Yarrow	1862	128
Cast-iron, Certain Methods of Treating, in the Foundry.	Z. Colburn	1865	77
Cement, Portland	H. Faija	1885	95
Central India Railway, Bombay, Baroda, and	C. Sanderson	1863	97
Channel Railway, The	P. F. Nursey	1876	17
Channels for the Conveyance of Sewage, The Forms and Construction of	J. Phillips	1874	145
Charcoal, The Conversion of Peat into Fuel and	C. E. Hall	1876	151
Charging and Drawing Gas Retorts by Machinery.	J. Somerville	1873	138
Charging and Drawing Gas Retorts, An Improved Method of	F. W. Hartley	1875	185
Charing Cross Railway Bridge over the Thames.	M. Parkes	1864	166
Charing Cross Railway, The Road Bridges of	„ „	1864	143
Cheap Patents, The National value of	F. W. Grierson	1880	145
Chelsea Bridge, The Construction of ..	G. G. Page	1863	77
Circular Tables	H. Hakewill	1865	147
Coal Gas, The methods employed in the determination of the Commercial Value and Purity of	F. W. Hartley	1869	100
Coal Gas, Apparatus employed for illumination with	W. Sugg	1869	134
Coal Gas, The Manufacture of	A. F. Wilson	1864	35
Coal Gas, Some Modern Improvements in the Manufacture of	R. P. Spice	1886	131
Coal-liming Process, Cooper's	J. A. Wanklyn	1884	167
Coal Mines, The Ventilation of	G. G. André	1874	23
Coal Slack, Utilisation of, in the Manufacture of Coke for Smelting.	G. M. Ward	1880	33
Colliery, The Underground Pumping Machinery at the Erin, Westphalia	H. Davey	1876	119
Colonies, Practical Construction in the	W. G. Ferrar	1875	53
Compressed Gas, Illumination by means of	P. F. Nursey	1881	57
Compression, Air	J. Steel	1876	65
Condensers, Surface	J. Louch	1861	96
Connection between the Shape of Heavy Guns and their Durability.	A. Rigg	1867	249
Construction, Modern Tramway	A. W. Jones	1879	79

Subject of Paper.	Author.	Published. Year.	Page.
Construction, Modern Roadway	H. S. Copland	1878	61
Construction of Chelsea Bridge	G. G. Page	1863	77
Construction of Modern Piers	J. W. Wilson, junr. ..	1875	29
Continental Intercommunication, English and	P. F. Nursey	1869	154
Continuous and Automatic Brakes, Hydraulic	E. D. Barker	1879	75
Continuous Brakes, Recent arrangements of	St. J. V. Day	1875	87
Continuous Railway Brakes	W. H. Fox	1872	112
,, ,, ,, ...	,, ,, ...	1873	33
Conversion of Peat into Fuel and Charcoal	C. E. Hall	1876	151
Cooper's Coal-liming Process	J. A. Wanklyn	1884	167
Cornish Pumping Engine, The Use of the	A. Fraser	1864	78
Cotton Press, The Accumulator	E. Matheson	1868	264
Cylinders, Equalising the wear in Horizontal Steam	W. Schönheyder ..	1878	45
Cylinders, Friction in Steam	P. Jensen	1870	17
Cyprus, Engineering Notes on	C. J. Alford	1880	131
D.			
Darien and the Ship Canal, The Isthmus of	Dr. E. Cullen	1868	52
Deep-Sea Lighthouses, Feasibility, and Construction of	C. Anderson	1883	45
Deep-water Entrances, Tidal Approaches and	J. B. Redman	1885	143
Defects of Steam Boilers and their Remedy.	A. C. Engert	1884	25
Dephosphorisation of Iron in the Puddling Furnace.	P. S. Justice	1885	169
Designing and Construction of Storage Reservoirs, The	A. Jacob	1866	225
Designs, Specifications and Inspection of Ironwork	H. W. Pendred	1883	87
Direct-acting Hydraulic Machinery ..	R. H. Tweddell	1877	95
Direct-acting Pumping Engines ..	P. B. Björling	1877	79
Disposal of Sewage, The	H. Robinson	1879	197
Distilling and Hoisting Machinery for Sea-going Vessels.	H. W. Pendred	1880	55
Distribution of Electrical Energy by Secondary Generators.	J. D. Gibbs	1885	49
Docks, Floating.—The Depositing Dock and the Double-power Dock.	J. Standfield	1881	81
Drainage and Water Supply to the Town of Fareham.	T. Buckham	1869	41
Drainage of the Fens, The	B. Latham	1862	154
Dundee Street Improvements and Drainage of Lochee.	A. Greig	1883	113

Subject of Paper.	Author.	Published. Year.	Page.
E.			
Earthworks, A New Method of setting out the Slopes of	C. J. Light	1873	216
Economics of Railway Maintenance ..	E. S. Crompton	1870	101
Economic Uses of Blast Furnace Slag	P. F. Nursey	1873	196
Elastic Railway Wheels	V. Pendred	1864	119
Electric Light Engineering, Notes on ..	C. H. W. Biggs and W. W. Beaumont	1882	23
Electric Telegraph Instruments	E. G. Bartholomew ..	1872	53
Electric Telegraphy, irrespective of Telegraphic Apparatus.	„ „ ..	1869	55
Electrical Batteries	„ „ ..	1872	77
Electrical Energy, Distribution of, by Secondary Generators.	J. D. Gibbs	1885	49
Electricity, The application of, to the ignition of Blasting Charges.	G. G. André	1878	123
Electricity, The Lighting and Extinction of Street Gas Lamps by	St. G. Lane Fox ..	1878	105
Enclosure of Lands from the Sea, and the Construction of Sea and other banks.	E. Olander	1862	25
Engineering Enterprise, American ..	A. Rigg	1885	21
Engineering Notes on Cyprus	C. J. Alford	1880	131
Engineering in India	F. C. Danvers	1868	137
Engineering of Malting	H. Stopes	1884	65
Engines, Direct-acting Pumping	P. B. Björling	1877	79
Engines for Mines, Recent Improvements in Pumping	H. Davey	1873	182
Engines for Town Water Supply, Pumping	„ „	1867	88
Engines, Gas	C. Gandon	1881	27
Engines, Obscure Influences of Reciprocation in High-speed	A. Rigg	1886	83
Engines on the Rimutakai Incline, New Zealand, The Fell	R. J. Alford	1882	121
Engines, Steam Fire, and the late trial at the Crystal Palace.	W. Roberts	1863	163
Engines, The Adhesion of Locomotive, and certain expedients for increasing or supplementing that Function.	V. Pendred	1865	207
Engines, The Use of the Cornish Pumping	A. Fraser	1864	78
English and Continental Intercommunication.	P. F. Nursey	1869	154
Equalizing the Wear in Horizontal Steam Cylinders.	W. Schönheyder ..	1878	45
Examples of Recent Practice in American Locomotive Engineering.	V. Pendred	1872	19
Exhaust Steam, Apparatus for Utilising the waste heat of	J. Atkinson	1878	167
Exhibitions as Aids to Engineering Progress, Value of The	S. Barnett, junr. ..	1883	75

Subject of Paper.	Author.	Published. Year.	Page.
Experimental Researches into the Nature and Action of Steam Boilers	T. Baldwin	1867	23
Experiments on the Strength of Materials, The Need of further	C. J. Light	1869	194
Explosion at Erith, and the Repair of the River Bank.	L. G. Moore	1864	183
Explosions, Steam Boiler	P. F. Nursey	1863	1
Explosive Compounds for Engineering Purposes.	„ „	1869	10
Explosive Compounds, Recent Improvements in	„ „	1871	108
F.			
Fareham, Drainage and Water Supply of the Town of	T. Buckham	1869	41
Feasibility and Construction of Deep-sea Lighthouses.	C. Anderson	1883	45
Fell Engines on the Rimutakai Incline, New Zealand.	R. J. Alford	1882	121
Fens, The Drainage of the	B. Latham	1862	154
Fire-clay Manufactures	W. H. Stevenson ..	1861	17
Fire Engines, Steam	W. Roberts	1863	163
Floating Breakwaters	T. Cargill	1871	146
Floating Docks: The Depositing Dock and the Double-power Dock.	J. Standfield	1881	81
Flues and Ventilation	A. H. C. Trewman ..	1876	91
Flues in Lancashire and similar Boilers, The Strength of	W. Martin	1882	157
Forms and Construction of Channels for the Conveyance of Sewage.	J. Phillips	1874	145
Friction in Steam Cylinders	P. Jensen	1870	17
Friction of the Slide Valve and its appendages.	T. Adams	1866	6
Fuel	P. F. Nursey	1864	1
Fuel and Charcoal, The Conversion of Peat into	C. E. Hall	1876	151
Fuel, Liquid	P. F. Tarbutt	1886	193
Furnace, The Blowpipe Flame	A. C. Engert	1884	185
G.			
Gas, Apparatus employed for Illumination with Coal	W. Sugg	1869	134
Gas Engines	C. Gandon	1881	27
Gas, Illumination by means of Compressed	P. F. Nursey	1881	57
Gas Retorts, An Improved method of Charging and Drawing	F. W. Hartley	1875	185
Gas Retorts, Charging and Drawing by Machinery.	J. Somerville	1873	138
Gas, The Manufacture of Coal	A. F. Wilson	1864	35
Gas, Modern Improvements in the Manufacture of Coal	R. P. Spice	1886	131

Subject of Paper.	Author.	Published. Year.	Page.
Gas, The Methods employed in the determination of the Commercial Value and Purity of Coal	F. W. Hartley	1869	100
Gas and Water Mains, The prevention of Leakage in	C. M. Barker	1869	79
Gas Works at Home and Abroad, Modern	H. Gore	1868	233
Giffard's Injector	L. Olrick	1865	280
Government Brake Trials	T. Maude	1875	129
Governors, Marine	L. Olrick	1862	104
Governors, Sensitiveness and Isochronism in	A. Rigg	1880	73
Guns, The connection between the Shape of heavy, and their Durability.	„ „	1867	249
H.			
Harbour Bars: their Formation and Removal.	H. F. Knapp	1878	139
Hauling Machinery, The new Pit and, for the San Domingos Mine in Portugal.	J. Bernays	1879	29
Horse Railways and Street Tramways.	H. Gore	1873	113
Hydraulic Continuous and Automatic Brakes.	E. D. Barker	1879	75
Hydraulic Experiments, the Roorkee ..	E. S. Bellasis	1886	41
Hydraulic Machinery, Direct-acting ..	R. H. Tweddell	1877	95
I.			
Ice-making Machinery	C. Pieper	1882	139
Ignition of Blasting Charges, The application of Electricity to	G. G. André	1878	123
Illumination by means of Compressed Gas.	P. F. Nursey	1881	57
Illumination with Coal Gas, Apparatus employed for	W. Sugg	1869	134
Improved method of Charging and Drawing Gas Retorts.	F. W. Hartley	1875	185
Improvements in Explosive Compounds, Recent	P. F. Nursey	1871	108
Improvements in Pumping-engines for Mines, Recent	H. Davey	1873	182
Improvements in Tin Dressing Machinery, Recent	S. H. Cox	1874	11
Incrustation in Marine Boilers	P. Jensen	1866	117
India, Engineering in	F. C. Danvers	1868	137
Induced *v.* Forced Draught for Marine Boilers.	W. A. Martin	1886	111
Indus, Steam Navigation on the	A. Warren	1863	139
Injector, Giffard's	L. Olrick	1865	280

Subject of Paper.	Author.	Published. Year.	Page.
Injector, The most Recent Improvements on the	J. Gresham	1867	266
Instruments, Electric Telegraph	E. G. Bartholomew ..	1872	53
Intercommunication, English and Continental	P. F. Nursey	1869	154
Intercommunication, Railway Train ..	S. A. Varley	1873	162
International System of Marine Course Signalling.	Capt. W. B. Barker ..	1884	47
Inundations of Marsh Land	B. Latham	1862	173
Iron, The Dephosphorisation of, in the Puddling Furnace.	P. S. Justice	1885	169
Iron, The Manufacture of	E. Riley	1861	59
Iron, The relation between the Safe Load and ultimate Strength of	Z. Colburn	1863	35
Iron, The quality of, as now used ..	E. Matheson	1867	168
Iron Roofs	A. T. Walmisley ..	1881	123
Iron and Steel Surfaces, The Preservation and Ornamentation of	G. Bower	1883	59
Ironwork, Designs, Specifications and Inspection of	H. W. Pendred	1883	87
Irrigation with Town Sewage	G. King	1865	84
Isochronism in Governors, Sensitiveness and	A. Rigg	1880	73
Isthmus of Darien and the Ship Canal	Dr. E. Cullen	1868	52
J.			
Japan, Railway Tunnelling in	T. M. Rymer-Jones ..	1881	101
Joints, Single- and Double-riveted ..	T. Baldwin	1866	150
L.			
Land and Naval Purposes, Signalling for	F. Wise	1863	117
Lartigue Single-rail Railway, The ..	F. B. Behr	1886	163
Laws, Decrees and Regulations relating to Mining Operations in the old kingdom of Sardinia.	C. J. Alford	1879	106
Leakage in Gas and Water Mains, The prevention of	C. M. Barker	1869	79
Lighthouses, The feasibility and construction of Deep-sea	C. Anderson	1883	45
Lighting and Extinction of Street Gas-Lamps by Electricity.	St. G. Lane Fox ..	1878	105
Liquid Fuel	P. F. Tarbutt	1886	193
Lochee, Dundee Street Improvements and Drainage of	A. Greig	1883	113
Locomotive Engineering, Examples of recent Practice in American	V. Pendred	1872	19
Locomotive Engines, The adhesion of ..	„ „	1865	207

Subject of Paper.	Author.	Published. Year.	Page.
M.			
Macadam for Roads, Modern Machinery for preparing	C. E. Hall	1879	51
Machinery and Utensils of a Brewery..	T. Wilkins	1871	10
Maintenance, The Economics of Railway	E. S. Crompton ..	1870	101
Malting, The Engineering of	H. Stopes	1884	65
Manufacture of Coal Gas	A. F. Wilson	1864	35
Manufacture of Iron	E. Riley	1861	59
Marine Boilers, Incrustation in	P. Jensen	1866	117
Marine Boilers, Induced *v.* Forced Draught for	W. A. Martin	1886	111
Marine Course Signalling, International system of	Capt. W. B. Barker ..	1884	47
Marine Governors	L. Olrick	1862	104
Marine Worms, Action of and Remedies for, at San Francisco.	J. Blackbourn	1874	111
Marsh Lands, The Inundations of ..	B. Latham	1862	173
Mechanical Firing of Steam Boilers ..	J. W. Pearse	1877	31
Mechanical Puddling	P. F. Nursey	1874	77
Mechanical Saws	S. W. Worssam, junr.	1867	196
Methods employed in the Determination of the Commercial Value and Purity of Coal Gas.	F. W. Hartley	1869	100
Milford Haven and its New Pier Works.	H. Davey	1872	89
Milling Machinery, Roller	J. H. Carter	1883	125
Mineralogy of the Island of Sardinia..	C. J. Alford	1879	93
Mining Operations in the old kingdom of Sardinia, Laws, &c., relating to	„ „	1879	106
Modern Bronze Alloys for Engineering purposes.	P. F. Nursey	1884	127
Modern Gasworks at Home and Abroad	H. Gore	1868	233
Modern Improvements in the Manufacture of Coal Gas.	R. P. Spice	1886	131
Modern Roadway Construction	H. S. Copland	1878	61
Modern Steel as a Structural Material	W. W. Beaumont ..	1880	109
Modern Systems of Generating Steam	N. J. Suckling	1874	39
Modern Tramway Construction	A. W. Jones	1879	179
N.			
National Value of Cheap Patents ..	F. W. Grierson	1880	145
Navigation on the Indus, Steam	A. Warren	1863	139
Need of further Experiments on the Strength of Materials.	C. J. Light	1869	194
Notes on Cyprus, Engineering	C. J. Alford	1880	131
Notes on Electric Light Engineering..	C. H. W. Biggs and W. W. Beaumont ..	1882	23

Subject of Paper.	Author.	Published. Year.	Page.
O.			
Obscure Influences of Reciprocation in High-speed Engines.	A. Rigg	1886	83
Opening Bridges on the Furness Railway.	C. J. Light	1885	119
P.			
Paints, The Use of, as an Engineering Material.	E. Spon	1875	69
Panama Railroad, The	Dr. E. Cullen	1868	39
Paris Exhibition, Visit to the	.. ..	1867	151
Patent Laws, The	C. D. Abel	1865	25
„ „ „	W. L. Wise	1870	45
Patents, The National Value of Cheap	F. W. Grierson	1880	145
Peat, The Conversion of, into Fuel and Charcoal.	C. E. Hall	1876	151
Peaty water, The Action of, on a Boiler	E. Riley	1862	45
Piers, The Construction of Modern ..	J. W. Wilson, junr. ..	1875	29
Pier Works, Milford Haven and its new	H. Davey	1872	89
Pits and Hauling Machinery for the San Domingos Mines in Portugal.	J. Bernays	1879	29
Portland Cement	H. Faija	1885	95
Practical Construction in the Colonies	W. G. Ferrar	1875	53
Preservation and Ornamentation of Iron and Steel Surfaces.	G. Bower	1883	59
Prevention of Smoke	A. C. Engert	1881	101
Prevention of Leakage in Gas and Water Mains.	C. M. Barker	1869	79
Priming of Steam Boilers	W. Major	1877	59
Propeller, The Screw	A. Rigg	1868	202
Propellers, Screw; their Shafts and Fittings.	H. W. Pendred	1875	151
Propulsion, The Theory of Screw ..	M. Sefi	1870	82
Puddling Furnace, The Dephosphorisation of Iron in	P. S. Justice	1885	169
Puddling, Mechanical	P. F. Nursey	1874	77
Pumping Engine, The Use of the Cornish.	A. Fraser	1864	78
Pumping Engines, Direct-acting ..	P. B. Björling	1877	79
Pumping Engines for Mines, Recent Improvements in	H. Davey	1873	182
Pumping Engines for Town Water Supply.	„ „	1867	88
Pumping Machinery, The underground, at the Erin Colliery, Westphalia.	„ „	1876	119
Q.			
Quality of Iron, as now used	E. Matheson	1867	168

Subject of Paper.	Author.	Published. Year.	Page.
R.			
Railway Amalgamation, State Railways and	G. Spencer	1872	43
Railway Axles, The Strength of Wrought-iron	T. Andrews	1879	143
Railway Brakes, Continuous	W. H. Fox	1872	112
,, ,, ,, ...	,, ,, ...	1873	33
Railway Bridge at the Place de l'Europe, Paris.	T. Cargill	1866	191
Railway Bridge over the Thames, The Charing Cross.	M. Parkes	1864	166
Railway Maintenance, The Economics of	E. S. Crompton	1870	101
Railway, The Channel	P. F. Nursey	1876	17
Railway Train Intercommunication ..	S. A. Varley	1873	162
Railway Tunnelling in Japan	T. M. Rymer-Jones ..	1882	101
Railway Wheels, Elastic	V. Pendred	1864	119
Railways, Horse, and Street Tramways	H. Gore	1873	113
Reciprocation, Obscure Influences of, in High-speed Engines.	A. Rigg	1886	83
Redhill Sewage Works, The	S. A. Reade	1868	168
Relation between the Safe Load and ultimate Strength of Iron.	Z. Colburn	1863	35
Repair of the River Bank, The Explosion at Erith and the	L. G. Moore	1864	183
Reservoirs, Storage, The Designing and Construction of	A. Jacob	1866	225
Rigidity, Strength and	W. E. Kochs	1865	69
River Pollution caused by Sewage Disposal.	G. B. Jerram	1886	217
Road Bridges of the Charing Cross Railway.	M. Parkes	1864	143
Roadway Construction, Modern	H. S. Copland	1878	61
Roller-milling Machinery	J. H. Carter	1883	125
Rolling of Ships	W. McNaught	1876	187
Roofs, Arched	C. R. von Wessely ..	1866	36
Roofs, Iron	A. T. Walmisley ..	1881	123
Roorkee Hydraulic Experiments	E. S. Bellasis	1886	41
Rural Sanitation	G. W. Usill	1877	113
S.			
Safe Load and ultimate Strength of Iron, Relation between	Z. Colburn	1863	35
Safety Valves for Steam Boilers, &c. ..	T. Baldwin	1867	23
Sanitary and Industrial, Water Purification	J. W. Pearse	1878	29
Sardinia, The Mineralogy of the Island of	C. J. Alford	1879	93
Saws, Mechanical	S. W. Worssam, junr.	1867	196
Screw Piles in the Construction of a Wrought-iron Bridge at Verona.	J. G. Horner	1867	52
Screw Propeller, The	A. Rigg	1868	202

Subject of Paper.	Author.	Published. Year.	Page.
Screw Propellers, their Shafts and Fittings.	H. W. Pendred	1875	151
Screw Propulsion, The Theory of ..	M. Sefi	1870	82
Sea and other Banks, The Construction of	E. Olander	1862	25
Secondary Generators, Distribution of Electrical Energy by	J. D. Gibbs	1885	49
Sensitiveness and Isochronism in Governors.	A. Rigg	1880	73
Sewage Disposal	H. Robinson	1879	197
Sewage Disposal, River Pollution caused by	G. B. Jerram	1886	217
Sewage, Irrigation with Town	G. King	1865	84
Sewage Matter, A new System of treating	H. Olrick	1883	23
Sewage, The forms and construction of Channels for the Conveyance of	J. Phillips	1874	145
Sewage, Utilisation of	B. Latham	1866	68
Sewage Works, Redhill	S. A. Reade	1868	168
Sewers, Ventilation of	B. Latham	1871	39
Ship Canal between the Atlantic and Pacific Oceans, The Surveys for	Dr. E. Cullen	1868	15
Ship Canal, The Isthmus of Darien and the	„ „	1868	52
Ships, Apparatus for Measuring the Velocity of	V. Pendred	1869	215
Ships, The Rolling of	W. McNaught	1876	187
Signalling for Land and Naval purposes	F. Wise	1863	117
Single and Double-riveted Joints	T. Baldwin	1866	150
Slag, The Economic Use of Blast-furnace	P. F. Nursey	1873	196
Slide-valve, The Friction of, and its appendages.	T. Adams	1866	6
Slopes of Earthwork, A new Method of Setting-out.	C. J. Light	1873	216
Smoke, Prevention of	A. C. Engert	1881	101
Soft *v.* Hard Water for Manufacturing purposes.	J. C. Fell	1884	103
Soil, Application of Steam to the Cultivation of the	B. Latham	1868	274
State Railways and Railway Amalgamation.	G. Spencer	1872	43
Steam, Apparatus for Utilising the Waste Heat of Exhaust	J. Atkinson	1878	167
Steam Boilers, The Defects of, and their Remedy.	A. C. Engert	1884	25
Steam Boiler Explosions	P. F. Nursey	1863	1
Steam Boilers, Experimental Researches into the Nature and Action of	T. Baldwin	1867	23
Steam Boilers, The Priming of	W. Major	1877	59
Steam Boilers, Mechanical Firing of ..	J. W. Pearse	1877	31
Steam Boilers, Water and its effect on	H. K. Bamber	1867	65
Steam Carriages	A. F. Yarrow	1862	128
Steam Cylinders, Equalising the wear in Horizontal	W. Schönheyder ..	1878	45
Steam Cylinders, Friction in	P. Jensen	1870	17

Subject of Paper.	Author.	Published. Year.	Page.
Steam Fire Engines, and the late trial at the Crystal Palace.	W. Roberts	1863	163
Steam, Modern Systems of Generating	N. J. Suckling	1874	39
Steam Navigation on the Indus	A. Warren	1863	139
Steel, Modern, as a Structural Material	W. W. Beaumont ..	1880	109
Stone-sawing Machinery	H. Conradi	1876	135
Storage Reservoirs, Designing and Construction of	A. Jacob	1866	225
Street Tramways, Horse Railways and	H. Gore	1873	113
Strength and Rigidity	W. E. Kochs	1865	69
Strength of Flues in Lancashire and similar Boilers.	W. Martin	1882	157
Strength of Materials, Need of further Experiments on the	C. J. Light	1869	194
Strength of Wrought-iron Railway Axles.	T. Andrews	1879	143
Sugar-making Machinery	P. F. Nursey	1865	155
Super-heating of Steam, and the various Appliances employed therein.	„ „	1861	36
Supply of Water to Towns	B. Latham	1864	199
Surface Condensers	J. Louch	1861	96

T.

Tables, Circular	H. Hakewill	1865	147
Telegraph Instruments, Electric	E. G. Bartholomew ..	1872	53
Telegraphy, Electric, irrespective of Telegraphic apparatus.	„ „ ..	1869	55
Testimonial to Mr. Alfred Williams ..	.. ..	1868	161
Theory of Screw Propulsion	M. Sefi	1870	82
Tidal Approaches and Deep-water Entrances.	J. B. Redman	1885	143
Tidal Energy, Utilisation of	A. Oates	1882	81
Timbering of Trenches and Tunnels ..	C. Turner	1871	90
Tin-dressing Machinery, Recent Improvements in	S. H. Cox	1874	11
Town Sewage, Irrigation with	G. King	1865	84
Towns, Supply of Water to	B. Latham	1864	199
Town Water Supply, Pumping Engines for	H. Davey	1867	88
Tramway Construction, Modern	A. W. Jones	1879	179
Tramway Rolling Stock, and Steam in connection therewith.	C. C. Cramp	1874	119
Tramways, Cable	W. N. Colam	1885	69
Treating Sewage Matter, A new system of	H. Olrick	1883	23
Trussed Beams	W. Parsey	1862	52
Tube Wells	A. Le Grand	1877	133
Tube Wells for large Water Supply ..	R. Sutcliff	1877	149
Tunnelling, Railway, in Japan	T. M. Rymer-Jones ..	1882	101
Tunnels, Timbering of Trenches and ..	C. Turner	1871	90

Subject of Paper.	Author.	Published. Year.	Page.
U.			
Underground Pumping Machinery at the Erin Colliery, Westphalia.	H. Davey	1876	119
Use of Coal in Furnaces without Smoke	C. F. T. Young	1862	66
Utensils of a Brewery, Machinery and	T. Wilkins	1871	10
Utilisation of Coal Slack in the Manufacture of Coke for Smelting.	G. M. Ward	1880	33
Utilisation of Sewage	B. Latham	1866	68
Utilisation of Tidal Energy	A. Oates	1882	81
Utilisation of Waste Mineral Substances.	E. Edwards	1861	82
V.			
Vacation Visits	.. ..	1878	119
,, ,, ...	.. ..	1879	141
,, ,, ...	.. ..	1880	89
,, ,, ...	.. ..	1881	121
,, ,, ...	.. ..	1882	119
,, ,, ...	.. ..	1883	85
,, ,, ...	.. ..	1884	119
,, ,, ...	.. ..	1885	113
,, ,, ...	.. ..	1886	153
Value of Exhibitions as Aids to Engineering Progress.	S. Barnett, junr. ..	1883	75
Value of Cheap Patents, The National	E. W. Grierson	1880	145
Velocity of Ships, Apparatus for Measuring the	V. Pendred	1869	215
Ventilation, Flues and	A. H. C. Trewman ..	1876	91
Ventilation of Buildings	J. W. Pearse	1876	97
Ventilation of Coal Mines	G. G. André	1874	23
Ventilation of Sewers	B. Latham	1871	39
Verona, Screw Piles in the construction of wrought-iron Bridge at	J. G. Horner	1867	52
Visit to the Paris Exhibition	.. ..	1867	151
W.			
Waste Heat of Exhaust Steam, Apparatus for Utilising the	J. Atkinson	1878	167
Waste Mineral Substances, The Utilisation of	E. Edwards	1861	82
Water and its effects on Steam Boilers ..	H. K. Bamber	1867	65
Water Purification, Sanitary and Industrial.	J. W. Pearse	1878	29
Water, Soft *v.* Hard, for Manufacturing Purposes.	J. C. Fell	1884	103
Water, Supply of, to Towns	B. Latham	1864	199
Water Supply, Pumping-engines for Town	H. Davey	1867	88

Subject of Paper.	Author.	Published.	
		Year.	Page.
Water Supply to the Town of Fareham, Drainage and	T. Buckham	1869	41
Water-tube Boilers	V. Pendred	1867	109
Wear in Horizontal Steam Cylinders, Equalising the	W. Schönheyder ..	1878	45
Wells, Tube	A. Le Grand	1877	133
Wells, Tube, for large Water Supply ..	R. Sutcliff	1877	149
Wheels, Elastic Railway	V. Pendred	1864	119
Worms, The action of Marine, and remedies employed in the Harbour of San Francisco.	J. Blackbourn	1874	111

LONDON:
PRINTED BY WILLIAM CLOWES AND SONS, LIMITED,
STAMFORD STREET AND CHARING CROSS.

UNIVERSITY OF ILLINOIS-URBANA
3 0112 110329676